Basic

# UNDERWATER CAVE SURVEYING

By

John Burge

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John Burge

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# SECTION 2

## CREDITS

Rarely does one ever undertake the writing and publication of a technical work without the assistance of others. Such is the case with **BASIC UNDERWATER CAVE SURVEYING**. I could not have done it entirely alone. It is quite a transition from notes, records, logs and files to a clean, organized, well-illustrated bound document which expresses the wills and ideas of the author.

After the first draft of this work I asked several people whom I respect and hold in high esteem and who are recognized as some of the foremost authorities in the world in cave diving to give me a very critical critique of this entire work ... and they really did! They all took me seriously and hacked away. However, they also gave me numerous suggestions for improving the organization as well as the content. I am especially thankful to these people for their input as well as their candor. I owe them many thanks for their time and contributions, and I wish to acknowledge them here.

| | |
|---|---|
| Collaboration ..... | Frank Howard |
| Cover ..... | Kären Flens |
| Critical Critique ..... | Jeff Bozanic |
| | Sheck Exley |
| | Frank Howard |
| | Joe Prosser |
| | Wes Skiles |
| Illustrations ..... | Kären Flens |

It was indeed a tremendous contribution on the part of each and every one of these stellar performers that made this book possible.

And last but certainly far from least, I wish to express my very sincere appreciation to my wife, Polly. Although she is a

diver and a favorite dive buddy, she has been a very patient "cave diver's widow" all these months while I was off blowing bubbles and laying line. She also gave me encouragement over the many months I was preparing this work and graciously tolerated the hours and hours that I spent sitting at my desk pounding away at my keyboard.

To each and to all of you....a very big **THANK YOU, VERY, VERY MUCH!**

John Burge

# SECTION 3

## FORWARD

It was a pleasant winter day in High Springs, Florida. My cave diving buddy, Frank Howard, and I had traveled down there to take some advanced cave dive training under the able tutelage of Wes Skiles. Wes was then the Training Chairman of the National Speleological Society Cave Diving Section and had given Frank and me several other courses in different levels of cave diving prior to this trip. We had arranged for private instruction, just as we had done in the past, because we knew that we would get more than our money's worth from Wes. On one side of the equation we both are very inquisitive and technical by training and are prolific with questions. On the other side of the equation Wes is not only a free form demanding individual, but I think he was somewhat intrigued by the "dynamic duo" of a couple of older guys with children much older than he, who had become so enraptured with the adventure of cave diving and all the technical aspects and special challenges it encompasses.

We were wrapping up the last of our assignments which was to survey an underwater cave, and we asked Wes for his suggestions for this final project. Frank and I both had visions of some big time deep penetrations with lots of stage planning and lengthy decompressions. We were big timing it. After all, there aren't many divers who are into surveying underwater caves and we were about to become members of the elite!

With a twinkle in his eye, Wes asked if we would survey Ginnie Spring. Now if you are a diver who has not yet been to central Florida and are not familiar with Ginnie Spring, you cannot really appreciate our reaction. Ginnie Spring is probably the most dived cavern in the world; it is probably the safest cavern in the universe; and we considered it the novice dive of novice dives within the realm of cave diving. Technically, it doesn't even qualify as a cave dive unless you dive it at night. Visibility at the time was just a mite short of infinity; maximum depth was 56 feet; and maximum penetration from the entrance was only about 90 feet. Real kid stuff!! Wes reasoned that because Ginnie is in fact so popular and is dived in fact by so many novice divers that Frank and I could really make a contribution to diver education and particularly to diver safety if we would just do this project. After having our egos salved sufficiently, we agreed to take on Ginnie for the survey. After all, we could do it at night after a day of real cave diving and simply knock out this little project the next evening and be on our way back up to the northern part of the state to venture into other caves we were anxious to explore.

Frank and I did the Ginnie Spring survey. Then we did it again. And we did it again. I don't know how many hours of bottom time we accumulated before we finally got all the data we thought we needed, nor do I recall how many times we got separated out of sight from each other, nor can I count the number of times we miscommunicated simple numerical data even though we have many, many dives together. Not only that, in spite of the numerous dives taking data and recording features, we even had disagreements on several of our sketches .... was it a boulder or was it an integral part of the karst structure of the cave? Since we both are rather opinionated and reasoned that ours was the right interpretation, it took even additional dives to resolve our differences if we wanted to be right. And we did.

We were several days delayed getting back up to the northern part of the state. As a matter of fact we had to reschedule that exploration trip - we simply ran out of time. We did complete the Ginnie Spring survey though. And we were proud of it. It was a good job and we got a lot of satisfaction (and more bottom time than we had anticipated) out of doing the project. If you ever visit Ginnie Spring in High Springs, Florida you will probably see a copy of it. More importantly, though, is the fact that this was a tremendous learning experience for both Frank and me and was the initial stimulus to our becoming much more involved in the surveying of underwater caves.

As we continued to explore more caves and as we expanded our survey projects, we began to avoid making the same mistakes more than a dozen times or so before we adopted a procedure or developed a technique between the two of us.

Since our Ginnie Spring experience, Frank and I have spent many, many hours together in underwater caves with Frank on one end of a tape and me on the other; with Frank paying out knotted line and my counting knots; with Frank doing a tie off and my placing a survey station marker. Since our little project at Ginnie, we have been developing procedures and techniques. We have been simulating emergencies, and learning from our experiences.

We began documenting our techniques, our procedures and our methodologies as we began to get into more complex projects. We have spent lots of time in our respective workshops making special equipment or equipment modifications and then trying them out in actual practice. We have bungled some, and we have come up with some good ideas. We feel as though we work well as a dive survey team .... that we have accumulated some valuable experiences.

Much of this became evident when I was asked to lead a workshop on underwater cave surveying at one of the semiannual cave diving workshops conducted by the National Speleological Society Cave Diving Section. I accepted on condition that I could interest Frank in participating with me. He did and we

did, and we thoroughly enjoyed it. We also were impressed by the lack of the basics of underwater cave surveying being recorded anywhere. Other than Sheck Exley, Wes Skiles, Stephen Maegerlein, and perhaps less than a handful of others, very few cave divers have taken the time and put forth the effort to record and document the procedures they might have developed. Had they done so, and if such procedures were more widely available, more divers would be encouraged to do cave surveying. Certainly it would be much easier for future underwater cave surveyors to build on such a knowledge base.

Herein lies our goal:

1. To encourage greater use of maps in dive planning as the cave diving population expands

2. To encourage more divers to participate in surveying and cartography and to make their results available to the rest of the cave diving community

3. To start the ball rolling toward the establishment of recognized standards in procedures, techniques and quality

We have taken the time and put forth the effort to document our knowledge base, and I wish to pass it along to you in hopes that you will accept it as just that .... a data base. We would encourage you to add to this knowledge and to record it. We would also encourage you, if you are a trained cave diver, to start surveying the caves you frequent. Far be it for us to represent ourselves as experts. We simply have enjoyed our survey experiences and hope that you and the rest of the cave diving community will be able to benefit from our efforts.

You must be interested in underwater cave surveying or you wouldn't be reading this book. If you aren't a trained cave diver, don't try it yet. Go take the specialized training for cave diving and get into it gradually. Cave diving is very dangerous for the untrained. It can be dangerous even for the trained and experienced if rules are bent and procedures are not followed. On the other hand, the risks can be held to an absolute minimum and certainly reduced to a very acceptable level for such a sport. This is what training and education are all about.

Frank and I are very conservative and safety oriented, and we regularly simulate emergencies for our own practice. However, only one short section of this book is devoted to safety techniques per se because we feel they should be incorporated into the basic procedures. Let me stress up front that above all .... above taking that last measurement, above getting the last segment, above widening our separation limits just a little bit further, above pushing the air just another 100 pounds .... above all else comes the first and foremost consideration of safety.

He who dives in caves a way
Can tangle with the worst
He'll live to dive another day
If he puts safety first

One last thing. We continue to keep records and document our ongoing projects. We will probably update this book as we find our data base expanding, and it is my intention to do a sequel on advanced survey and cartography techniques as the cave diving community continues to advance the state of the art. We welcome your critique and contribution of any additional data, experiences and procedures that you feel might be developed to the point of including them in any future publication on this subject. Any contribution included in such a publication will be recognized, and appropriate credit will be given to the author.

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Although I am the sole author of this work, I could not have done so without the able collaboration, support and encouragement of my very good friend and dive buddy, Frank Howard. The material developed for this book is the result of both our efforts. Neither one of us could have done it alone.

We both wish you the best in your survey projects and hope that you get even half the pleasure and satisfaction from your survey projects as we have. Dive safely!

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PADI Master SCUBA Diver Trainer

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# SECTION 4

## INTRODUCTION

One might ask, "Who would ever have need to survey an underwater cave?" Well, if you are reading this book, one obvious answer is, **YOU.** You probably are a diver or have an interest in diving with a curiosity toward exploring underwater caves. Perhaps you are even a cave diver. If you are, then hear this: **You have never really seen a cave until you have surveyed it!** I can tell you from many, many personal experiences that I have consistently underestimated the complexity and the beauty of caves that I have dived numerous times before I surveyed it. Furthermore, I would consistently overlook features, alcoves, possible leads to new unexplored passages and even vertebrate remains time and time again until I had to take a measurement or do a sketch. Even though I am a rather observant person, I would look right past some of the most interesting and fascinating aspects of virtually every cave I penetrated until I got involved in surveying. To do even a simple survey of an underwater cave is to get to know it - intimately - to enjoy it. Not only that, the process is relatively easy. There are a few inexpensive special tools involved, but for the most part, the process is procedural. All it takes is the desire and the patience and the willingness to follow some simple procedures which will be outlined in subsequent sections. If you are willing to invest the time, if you are a reasonably competent cave diver, and if you will pay attention to detail, you can survey.

Surveying a cave forces you to look at it much more closely, in detail. And to look at it more closely is to enjoy it more. So as a surveyor you benefit. But why should anyone else have any use for a map of an underwater cave? Here again the answer is, **YOU.** Obviously, if a map were available of a cave you have never penetrated, with its use you could familiarize yourself with the cave size and features and plan a much safer and better organized dive. With such basic information as depths and flow you can estimate rather accurately your turn times by applying the following formula:

$$[(D \div 34) + 1] \times SBR = A$$

**Where:** D = Average depth in ft
SBR = Surface breathing rate in cu ft/min
A = Air consumption rate in cu ft/min at depth

Use 34 for fresh water, 33 for salt water

Then by dividing the air you plan to use to turn time by A, your

approximate turn time in minutes is determined.

For example, you study a map of "Spooky Cave" and note that floor depth is fairly constant at about 50 feet for the first 1500 feet or so. For this exercise make the following assumptions:

- You can stay 5 feet or more off the floor, which you determine from ceiling heights and cross sections.
- You are diving double 80's starting at 3100 psi.
- You are using the 1/3 air rule.
- The air hog on the team (that's me) has a SBR of 0.8 cu ft/min.

You apply the formula as follows:

$$[(45 \div 34) + 1] \times 0.8 = 1.85 \text{ cu ft/min}$$

Rounding 3100 down to 3000 and dividing by 3 yields 1000 psi or 53 cu ft planned air use to turn (2100 psi remaining). Then 53 cu ft ÷ 1.85 cu ft/min = 28.6 or approximately 29 minutes to turn time. If your swim rate is about average (we usually average about 40 ft/min on a no-flow or low-flow first time penetration), then you should expect to turn the dive at about 29 X 40 or between 1100 and 1200 ft penetration. A handy bit of information indeed. Not only that. If this were your first dive of the day, you would know that you would be well within the no decompression limits. If, on the other hand, this were a repetitive dive, you would know precisely what your decompression schedule should be - ahead of time - and could plan your decompression air or $O_2$ accordingly.

Now this book is not being written as a treatise on cave diving or air management principles - you should already be well versed in these areas. But this little discussion simply illustrates one of many, many ways in which underwater cave maps can be of use to the diver - much more thorough and safer dive planning, for example.

And the diver is not the only one with an interest in the meandering of these subterranean passages. Consider the interests of the archaeologists, the geochemists, the hydrologists and the paleontologists. To quote Dr. Art Palmer of the Department of Earth Sciences, N.Y. State University College, Oneonta, N.Y., who is one of the foremost authorities in his field ....."Mapping alone is tremendously useful. Studies of water and rock - even a greater contribution." Consider also the value of underwater cave maps which include not only size, shape, directions, depths and features, but also the locations of fossils, rock samples and water flow and chemical analysis points. There is also supplemental information that can pin point the ages and origins of bedding planes and a host of additional data that can be captured photographically and referenced to an exact location.

And then there is the land owner - commercial and otherwise. There are numerous applications of data obtained by surveying underwater cave passages as applied by the owners of the acres above. Some tend toward conservation, some tend toward recreation, and still others tend toward more basic economic considerations.

And that's not all .... by any means. Consider this application. A popular spring dive site had developed a wide reputation for having a cave that killed divers. Now you and I both know that caves don't kill divers. Divers kill divers. Even more specifically, ill trained, misinformed, macho and stupid divers kill divers. However, there had been a very large number of fatalities at this particular site, and it was dived by thousands of neophyte divers each year. We chose to survey it, not because of hydrological or paleontological interests, but simply because of our interests in diver education and concern for diver safety.

During the survey of "Killer Cave" (actual name withheld), we discovered several phenomena regarding some very tricky currents, optical illusions and deceptions and other idiosyncracies of this particular spring which could seriously disorient an inexperienced diver. We were able to study and document the physical properties of the spring and translate these data from survey format to maps, illustrations, notes and explanations. Now this information is available to every diver who wishes to enter "Killer Spring." With this knowledge perhaps fewer divers (hopefully no divers) will experience surprises which have contributed to the fatalities there in the past.

Now I ask you, Is such a survey worth while? Why certainly. No one would disagree.

The list of applications of underwater cave survey data goes on and on. There certainly is a need for the survey and mapping of underwater caves.

One could go on and on about the growing need for more maps of underwater caves, but for now, let's get on with the how-to-do-it part of this book. You will find that the procedures we have developed and which I describe here in a do-it-yourself approach are simple and easily executed. In fact, you will probably find that surveying underwater caves will add a tremendous amount of excitement and loads of additional fun to your cave diving!

# SECTION 5

## THE SURVEY PROCESS

### INTRODUCTION

What is meant by the survey process? The process is simply the combination of all the individual steps necessary to make the transition from picking a cave to hard copy in the form of a map.

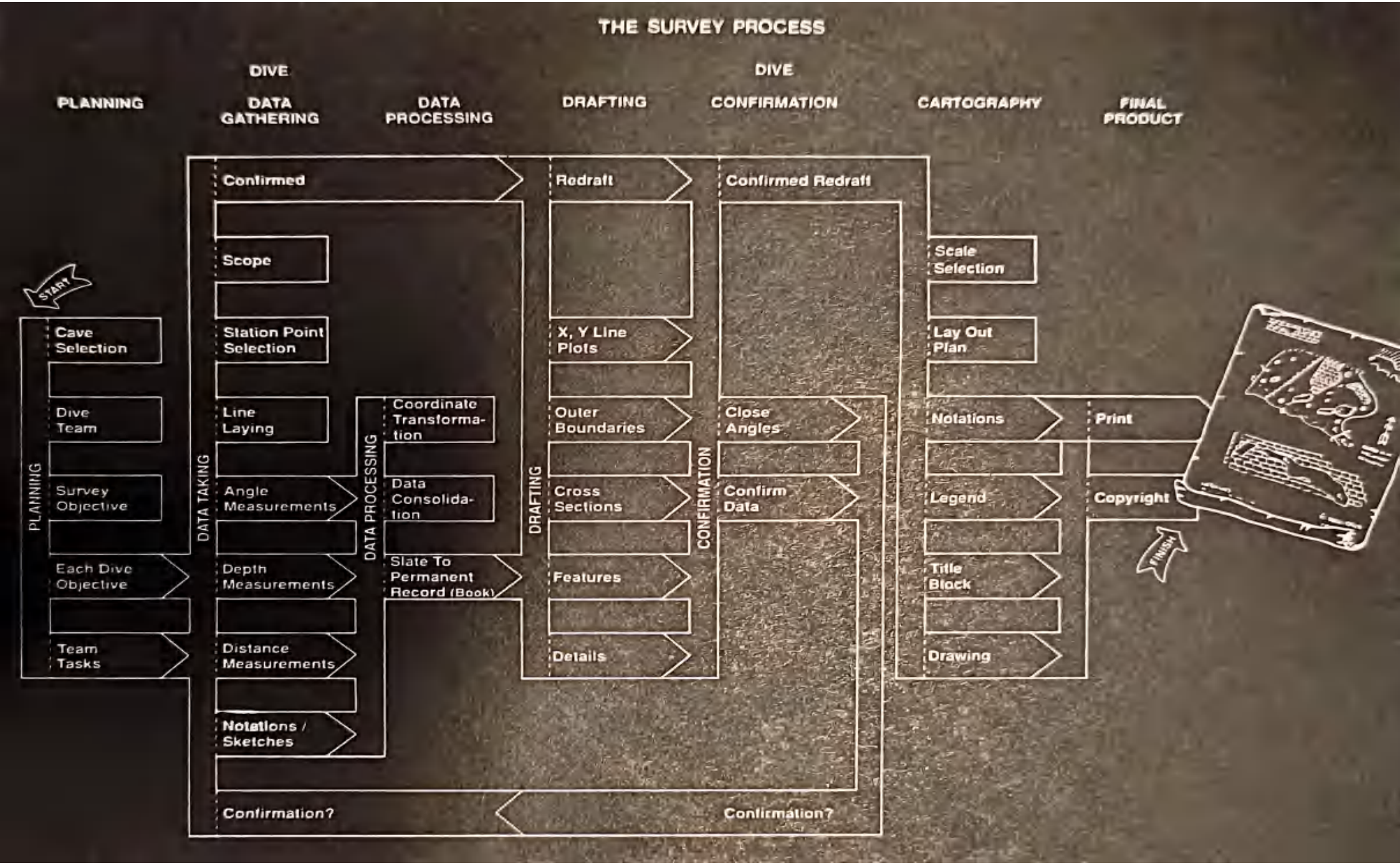
Keep in mind that a map, like this book, is a form of communication - but more abstract than a mere expression of thoughts and words. The underwater cave surveyor's task is a more challenging one. Why? Because his task is to convey an image of spatial information from an optical observation to the mind of the reader. More encompassing than a mere drawing of an object to convey such an image, which we do also, but the cave is a void .... much more difficult to express. Not only that, our voids are complicated, dark holes in the ground that are full of water - and sometimes other things as well!

Since we can't just draw a void, we must resort to defining the void by its outer limits which are typically expressed as walls, floor depths, ceiling heights and cross sectional representations. Short of actual photographic or video reproduction of what is seen, the map is the only means of conveying this three dimensional information.

Also, the gathering of all the data necessary, one bit at a time, to transform observations into hard copy is done in the most difficult environment possible. The task is not a difficult one, but it is complex and presents many potential problems and questions. Unfortunately, there are no simple answers to these dilemmas. There are, however, the determination and the creativity of those who rise (or dive) to meet the challenge. Use of the proper procedures and tools allows us to take on this multifaceted process a step at a time. Anyone can do it.

The task is a complex one, and such a task typically is best accomplished in a series of steps - sometimes sequentially and sometimes concurrently. Such is the case here. However, the task may appear to be more complex than it actually is. In practice it is merely a succession of easy steps well within the capabilities of most divers.

We have developed a definition of each step which must be performed by the underwater cave surveyor and have sequenced these steps in the logical order of accomplishment. By breaking up the total project (surveying an underwater cave) into


THE SURVEY PROCESS
PLANNING
DIVE
DATA GATHERING
DATA PROCESSING
DRAFTING
DIVE
CONFIRMATION
CARTOGRAPHY
FINAL PRODUCT
START
Cave Selection
Dive Team
Survey Objective
Each Dive Objective
Team Tasks
PLANNING
DATA TAKING
Confirmed
Scope
Station Point Selection
Line Laying
Angle Measurements
Depth Measurements
Distance Measurements
Notations / Sketches
DATA PROCESSING
Coordinate Transformation
Data Consolidation
Slate To Permanent Record (Book)
DRAFTING
Redraft
X, Y Line Plots
Outer Boundaries
Cross Sections
Features
Details
CONFIRMATION
Confirmed Redraft
Close Angles
Confirm Data
Confirmation?
Confirmation?
Scale Selection
Lay Out Plan
Notations
Legend
Title Block
Drawing
Print
Copyright
FINISH

individual steps and then executing each step in the proper sequence, the complete task can be accomplished. The progression of accomplishing each step from start to finish through the proper sequence is the survey process. To illustrate this concept graphically, let's examine Figure 5-1.

Note that there are seven distinct groups of steps or phases to be accomplished in order to make the transition from "start" to "finish." Note also that only two groups of steps involve diving! The other five are done on land, not necessarily at the dive site, either before or after the dive groups. If you study each step carefully and envision at this point what is involved, you will realize quickly that the least time in the process is involved in diving operations. The time consuming elements are the planning steps and the drafting steps, simply because both of these groups are iterative. That is to say, done properly, you will plan and replan; you draft, reconfirm and redraft. If one does not plan properly, his techniques and methodologies will be inefficient; if he does not draft, reconfirm and redraft, he will have inherent unresolved errors. The resulting product, therefore, will be less accurate. He may draw a pretty map, but the quality will be low. Quality is discussed in more detail in a later section.

One begins to recognize at this point that the survey process is far more than wiggling into a wet suit, slinging on a set of doubles and jumping into a spring with your handy dandy compass and a loaded line reel. **Not hardly!** If you aren't ready to spend the hours it takes to do even a simple survey in crunching data, drafting, verifying and coping with the rigors of cartography .... then don't take up surveying. If you are going to be one who takes a lot of data; puts it into a book; and stores it is his dive locker, then why bother? If you don't intend to produce the end product - an underwater cave map - save your efforts and spend them on sightseeing and exploring. Personally, I feel it is very rewarding. **It's exciting, and it will give you a tremendous sense of accomplishment; and, even better, others can benefit from your efforts!**

To elaborate further, we shall take a walk through the complete survey process step by step. First, however, let me put in context a framework of standards by which cave surveys are categorized regarding accuracies.

## ACCURACY OF SURVEY PROCEDURES

Here it is appropriate to dwell a little on the accuracies of cave surveys and the standards by which the accuracies are expressed. For underwater caves, specific standards have never been developed; however, such standards do exist for dry caves. A number of years ago the British Cave Research Association developed a set of standards expressed in terms of grades of accuracy and classification of survey detail. The fundamental

| | |
|---|---|
| Grade 1 | Sketch - Low accuracy - All measurements estimated |
| Grade 2 | Higher grade sketch than Grade 1, but less than Grade 3 |
| Grade 3 | Magnetic survey (compass)<br>Angles measured ± 2.5 degrees<br>Distances measured ± 50 cm or ± 1 2/3 ft. |
| Grade 4 | Higher grade survey than Grade 3, but less than Grade 5 |
| Grade 5 | Magnetic survey (compass)<br>Angles measured ± 1 degree<br>Distances measured ± 10 cm or ± 1/3 ft. |
| Note: | BCRA Grades go higher but Grade 5 is considered the highest grade attainable underwater given the current state of the art. |

Fig. 5-2 BCRA Standards of Accuracy

| | |
|---|---|
| Class A | Details and Features based on memory |
| Class B | Details and features estimated and recorded in the cave |
| Class C | Details measured at survey stations |
| Class D | Details measured at survey stations and wherever necessary to show significant change or feature |

Fig. 5-3 Classification of Survey Detail

reason for having any standards at all is that the map user has no way of knowing exactly how accurate a map is without such standards. For the map to be of maximum value, however, the user should be able to have an idea of the accuracy based on an understanding of the methods and techniques used to take the survey data. A recap of these grades of accuracy is shown in Figure 5-2 and apply to the accuracy of measurement of the location of the survey stations along the dry cave traverse. In an underwater cave, the traverse is the equivalent of the survey line or perhaps even the guideline. Figure 5-3 tabulates the classification of detail on the map by the method of survey data taking on detail. Figure 5-4 then combines the tables in Figures 5-2 and 5-3 and tabulates the combinations of recommended grades and classifications. Since the British Cave Research Association prohibits the publication of these standards without the accompanying notes, much like an accounting firm issuing audited financial statements, a more complete reproduction with accompanying notes is included in APPENDIX A.

It should be emphasized that a higher grade survey does not necessarily make a given map any better than a lower grade. The grade classification merely expresses to the user an understanding of the inherent accuracies of the methods and techniques used to take the data in the survey. A "stick map," typically done by cave divers on initial or early explorations, for example, would probably be a grade 2 or 3 with a classification of A or B. Grade 3 would be questionable due to the fact that distances are almost always measured by knotted nylon line which has a stretch coefficient substantially greater than grade 3 tolerances. Normally, cave divers do not dive with a tape unless they intend to take very accurate measurements. There are some "stick maps" done by early explorers such as Exley and Smith, however, that have been done with tape, and their accuracies are excellent.

| | |
|---|---|
| Grade / Class | 1A 1B |
| Grade / Class | 3B 3C |
| Grade / Class | 5C 5D |

Fig. 5-4 Grade/Class Combinations

Likewise, the generation of a firm grade 3 or 4 requires the use of tape measured distances, and front/back azimuth angle measurements and slant range corrections. A grade 5 survey requires not only the techniques of grade 3, but verification of azimuth angles and confirmation of survey station location by triangulation. Needless to say, very few grade 5C or 5D surveys

have ever been done - under water! But they have been done - by the author - and they are very, very time consuming.

Recognizing that the survey process can be scaled up or down to accomplish various grade levels by the application of various data taking and verification techniques, let us now continue stepping through the process, a phase at a time.

## THE PLANNING PHASE

Just like monopoly, the game begins at "start," or selecting a cave. Pretty basic, right? You can't survey a cave without first selecting one. However, if you are not an experienced underwater cave surveyor, you would be well advised to pick a cave, or part of one, that is structurally simple, shallow depth, low current and silt free. Why? Because structural complexity, depth, high flow and silt all present difficulties which have to be dealt with simply to dive safely. With the added dimension of survey task loading, something is more than likely to be sacrificed - either safety or survey quality - and we want both at the expense of neither. Make your first survey a simple one.

If you are experienced, of course, the selection criteria is driven by the objective. The techniques and methodologies will be selected or developed for the optimum balance. If the survey data taking is to be done on an initial penetration and exploration, the survey will probably be the secondary objective whereas penetration, exploration and the laying of new line will probably be the primary objective.

In this case the resulting survey or the data taking phase would be done on exit and would take the form of a "stick map" with just the basic DAD or Depth, Azimuth and Distance information supplemented with other brief notes on sidewall data. All distances would undoubtedly be measured by knotted line, and azimuths and depths would probably be taken and recorded only once. Angles would not be confirmed, and verification would not be done. The survey would be "open loop" so to speak.

On the other hand, if the primary objective is the generation of a higher grade map (tighter tolerances, closer accuracies, more detail) then different techniques would be used because the objective would be different. Higher grade surveys require different techniques which will be treated here. We will cover all the basic techniques before we are through, but the survey process described here is oriented toward the completion of surveys up to grade 5D as set forth by the British Cave Research Association.

Once cave selection has been made, the objectives of the survey must be determined in order to plan for the methods and techniques to be applied. A stick map objective is on one end of the spectrum, and a very accurate, very detailed map with hordes

of scientific notations is on the other end. The dive team typically would have a common survey objective in mind, and the objectives would determine the techniques to be employed.

After the team is assembled and the survey objectives are established, it is time for dive planning with specific objectives for each dive and specific tasks set out for each team member. We strongly recommend that each team member actually write each task and the sequence of accomplishment on his slate. We also would urge beginners literally to walk through their planned dive and simulate the accomplishment of every task. Communicate as you would under water. This "dry run" will be a tremendous aid in disclosing those areas which might be planned inadequately.

## DIVING - THE DATA GATHERING PHASE

Now you are ready for the first diving phase. Here, unless you are doing a stick map, we recommend at least one dive be made simply to scope out the project. It is here that you should determine what special tools or supplies will be needed. For example, if easily accessible and properly spaced natural tie points are not readily available, fasteners for station marker placement may be required. Other factors such as silt or flow must be considered in determining the best sequence of events. You may not mind a cave exit in silt, but you certainly add another degree of difficulty if you plan to survey on exit of a silty cave. Surveying inbound in optimum visibility certainly makes more sense. And on and on.... We have found that we are always ahead of the game and far better planned by making an initial dive to "scope" the project.

Once the project is scoped, the special tools are assembled, and the task sequence is established, the key to the process begins - the taking of the actual survey data. The survey line is laid and tied off at appropriate points. Actual measurements are then made by either knotted line or tape, depths are taken with a depth gauge, and directions are taken with a compass. The techniques of taking and recording these data and the numerous ramifications such as task loading, communications, station point location and the like will be discussed in the section on Techniques and Methodology.

After each survey dive or any dive to gather data, each diver surfaces with a slate full of notations consisting of completed tasks, measurement data, sketches and supplemental notes recorded in a predetermined format and cave survey "shorthand." Data is also in your memory at this point, and any data recording left for memory should be done immediately. A single or many, many dives may be required to proceed to the next phase. In any event, we cannot over emphasize the importance of recording data in an organized format with clear, legible notes and sketches. Reliance on one's memory should be held to an

absolute minimum. At this point you have a slate or slates full of data - on the surface.

## THE DATA PROCESSING PHASE

You now enter the data processing phase wherein you need to translate the information from the slate into a more useful format necessary to proceed to the drafting phase. This means that you must reorganize all measurement data from each diver's slate and consolidate it into the sequence in which it must be used later. You must also go through the mathematical process of converting three dimensional data from polar coordinate format, that is X, Y and Z, into a rectangular coordinate format, that is only X and Y, so it can be expressed in two dimensions on a single plane - a map. The mathematics of accomplishing this is treated in the section on Crunching Data. Additionally, all shorthand notations and sketches need to be translated, developed and refined to the point where they can be permanently recorded for future use. This is also very important, and you should use a permanent note book. We have found that a plain, 3-ring note book binder with 1/4 inch quadrille paper and section separators keeps our data well organized and permanently recorded. We also nearly always do these data processing steps at the dive site and we always do it the same day as soon after the dive as possible. The vividness of memory fades with time, and you will need to compare data between the members of the dive team while the team is still together.

Once the data is processed and permanently recorded, one member of the team should take custody of the note book and make duplicates for each member of the team. Seems unnecessary doesn't it. Not so.... Consider this. Frank lives in Missouri; I live in Florida. We need to communicate from time to time as we proceed through a survey project. (The first two phases of our Twin Cave project took us nearly a year, and we still plan at least two more phases.) It would be impossible for us to work together long distance without each of us having identical data bases. This applies whether the team members live a thousand miles apart as we do, or just across town.

## THE DRAFTING PHASE

After the data processing phase has been completed and all the data is refined and permanently recorded, you proceed to the drafting phase. Sometimes we start this process on site. Sometimes we wait till we get back to the hotel or even back home. We always try to do a first draft as soon as possible, however. When you do it on site, it usually will be because you need the line plots or circumsketches to use as the baseline for taking data on a repetitive dive.

The first draft of every map regardless of the grade and

classification level of the survey will be the line plots. This is the process of laying out the X and Y coordinates of each survey station on a grid of quadrille or graph paper. The plots may be done by coordinate transformation or simply by the azimuth angles and distances between survey stations with a protractor and a rule. The line connecting all survey station points is a replica of the actual survey line or traverse as it would be called in a dry cave. This plot then serves as the reference for filling in the outer limits or walls of the cave as well as reference for locating and positioning of all detail and features to be included on the map.

At this point in the process, depending on the grade of survey being performed, you may have all the data necessary to proceed to the cartographic phase and then final printing. Such would probably be the case with a stick map or grade 1 or 2 survey. However, for a good grade 3 or higher or for a D classification, the confirmation phase must be completed. You will find typically that large rooms, irregular side walls or, frequent significant variations in passage geometry require additional data taking.

If additional data taking is required, we have concluded that the most efficient method is to convert the data to line plots, determine exactly what additional data needs to be taken, and lay all this out on a slate prior to the next dive. This method allows you to divide tasks between divers. We suggest you make it a practice also to lay out your line plots on slate to scale which will allow you to measure details much more precisely between survey stations and sketch with amazing accuracy. As a matter of interest, we have actually taken photographs of passages where we have sketched cross sections to verify results and to experiment with photographic techniques which could enhance the speed and accuracy of data gathering. The fidelity of representation was consistently very, very accurate.

**REDIVE - THE CONFIRMATION PHASE**

From this phase, you proceed either to the cartography phase, to the confirmation phase or recycle to the data gathering phase. Assuming you are doing a high grade survey or a lower grade survey of complex geometry, or working in difficult conditions such as limited visibility, you undoubtedly will recycle for additional data. As mentioned previously, the preparation for this dive, or series of dives, entails the laying out of line plots, to scale, on slates. This helps you to determine the specific tasks to be performed in order to gather the data required. Also, the tasks are segregated by individual and team assignments. For example, sketching sidewalls in between survey stations or sketching a passage cross section at a survey station is a single diver task, whereas tape measurements typically require a team to avoid excessive task loading. Segregation of tasks also allows for planning to optimize the

dive. If the dive profile involves different depths, for instance, the deeper tasks would be done first - the shallower tasks during the latter part of the dive. Logical, isn't it? Optimize the data gathering process while you maximize safety.

A point on safety here, though this subject is treated more thoroughly in the section on Safety First. It is this stage of the dive planning where safety must be planned into the dive procedures. When tasks are segregated into individual diver tasks, the plan must include procedures which preclude the compromise of the buddy system. It is much, much too easy for each diver concentrating on his own tasks to get totally preoccupied and lose the sensitivity for his buddy's position. Before we started planning proximity of tasks into our task assignments, we would too often find ourselves separated, out of sight, or so far distanced that buddying up in an air emergency would have been difficult if not impossible. After simulating a couple of problems, however, we now plan proximity into the process and deem this to be the most basic consideration in the development of procedures .... even to the point of having a team member serve solely as a safety diver if necessary. Depending on circumstances, it may even be necessary to include two safety divers: one to watch the surveyors and one to watch the "watcher," since the surveyors could have difficulty watching the safety diver.

After the data gathering phase has been recycled and all data has been collected, processed, recorded and put into draft form, the odds are that the loops don't close to within the tolerances you seek. If you are striving for a high grade 3 or grade 4 or 5, you can bet on it!

And herein lies the need for a verification or confirmation phase. Lower grade surveys don't require this; however, higher grade surveys cannot be accomplished without it, though verification does not necessarily have to be done in the cave. Consider the survey of a large room 100 feet across. If we lay a line around the circumference tied off at six stations; and we plot on graph paper a hexagon connecting all six stations; and the loop closes on paper to within ± 50 cm (1 2/3 feet); you can have a very high confidence that all six angles measured are within ± 2.5 degrees and that all six legs were measured to within ± 50 cm thereby assuring that all six survey stations are located on the map to within ± 50 cm of their actual positions as required for Grade 3. See figure 5-5.

On the other hand, take the same scenario where the line plot closes only to within 5 feet of the starting point. You can force fit the data cartographically and generate a pretty map if you are artistic. However, it will not be a grade 3 or higher survey, and the error or errors must be resolved to close the loop either by redoing the survey data gathering or by triangulation. That is measuring the azimuth and or distances of several radials from the starting point, station 00, and one or

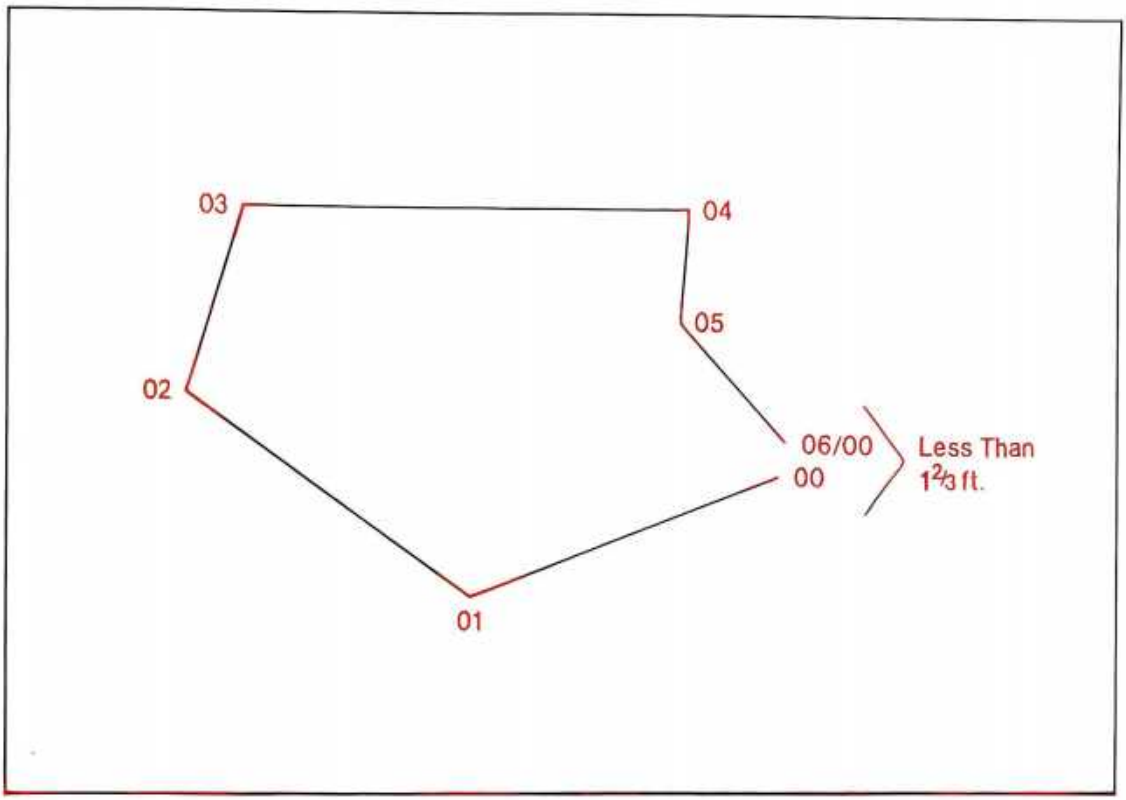



Fig. 5-5 Six point line plot - Gr 3/ Closed loop

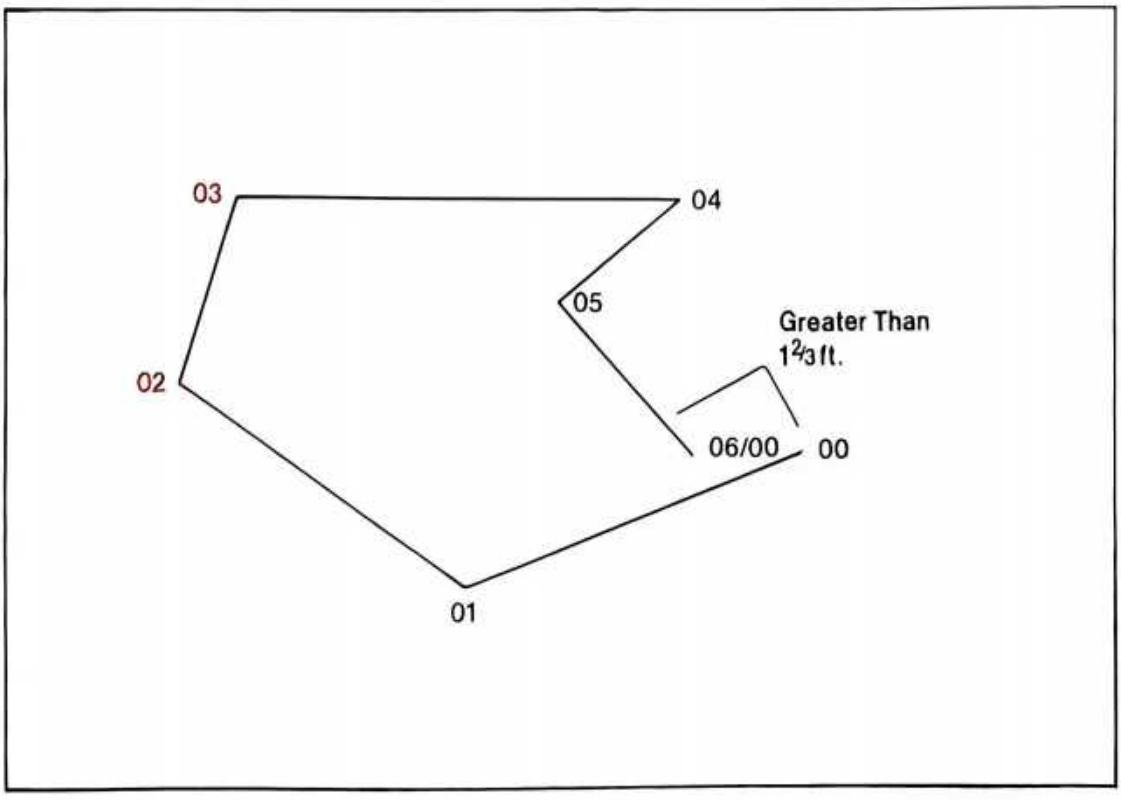



Fig. 5-6 Six point line plot/ Open loop

more cross radials or diagonals. See figure 5-6.

In comparing the illustrations in Figures 5-5 and 5-6, you can see that the error was made in measuring the angle inscribed by 03/04/05. A recheck of radial 00/05 and a diagonal check of 02/05 would locate the error, and the loop could be closed.

In order to qualify as a grade 5, the accuracies must be within ± 10 cm or about 4 inches and ± 1 degree. Obviously, a great deal of tape measurement and triangulation is required. See Figure 5-7. This process is very, very time consuming; however, these accuracies have been achieved by the author. Nevertheless, unless one is developing technique or surveying a room to meet the challenge, we feel that a grade 5 is at the very limit of achievability using compass and tape under water.

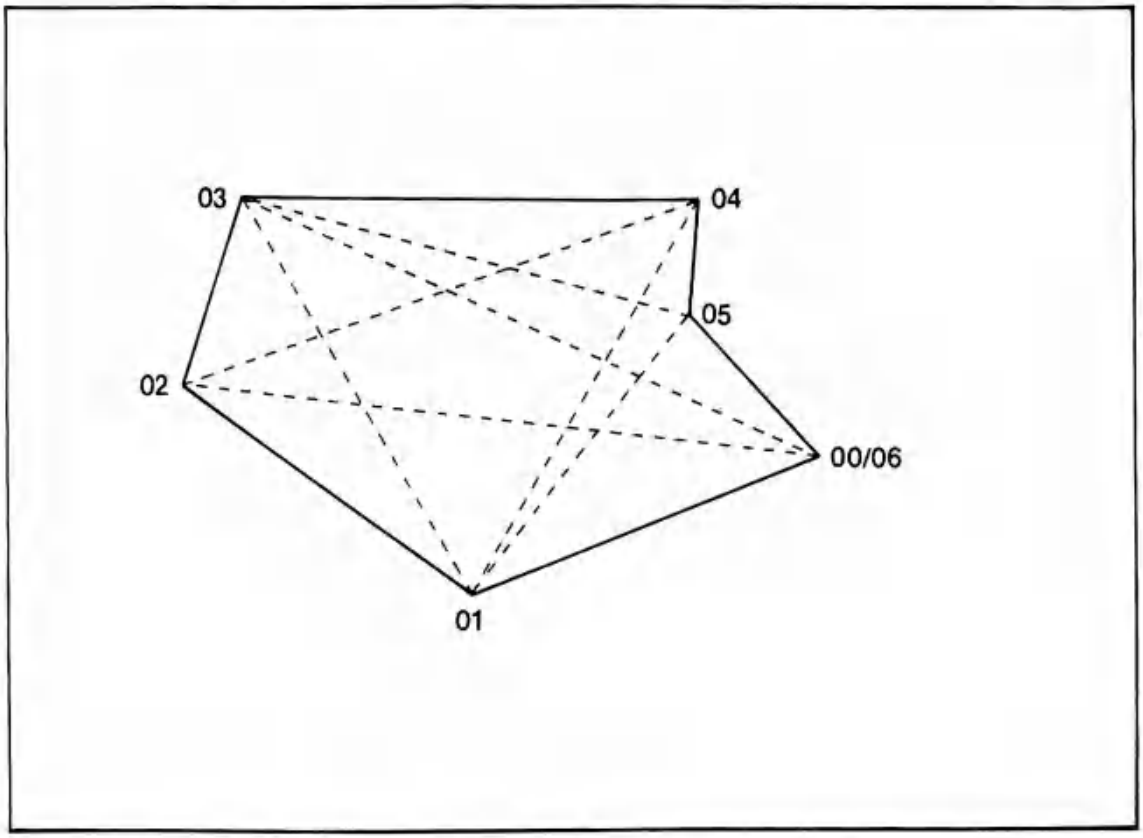



Fig. 5-7 Triangulation Required for Gr 5 Accuracy

This type of verification, of course, must be done in the cave and requires additional dives. Obviously, you can see the advantage of taking adequate data at the outset in order to locate potential errors during the initial drafting phase without having to redive.

Verification and confirmation of other data such as features and cross sections can be done by duplicating tasks among the team members. The objective, of course, in an ideal situation would be to gather all data in sufficient detail and duplication

such that errors can be resolved on the drawing board rather than having to return to the cave on a redive. This is the ultimate, however, and redives are frequent on higher grade surveys.

## THE CARTOGRAPHY PHASE

Having completed the confirmation and verification process, you now proceed to the cartography phase. This is where you really begin to see the project come into reality and literally unfold before your eyes. This is the exciting part!

Webster defines cartography as "the science or art of making maps." Applied here it is the transformation of data, notes, sketches and drafts into a reproducible document in the representation of a cave. The cartographic process, unless you have formal training in drafting or graphic art, will pose some interesting challenges. Not that anyone can't simply sit at a drafting board and draw. We all can. However, the process of selecting scale, developing balanced layouts, lettering, determining line widths, developing notes and legends, applying the correct symbology and selecting the proper materials for the reproduction process all play together to produce an accurate, legible, usable, aesthetically pleasing informative document. If you are not trained in the field and have no experience here, you probably haven't given much thought to line widths, title blocks and borders much less the application of unique symbology which at first looks like hieroglyphics to convey information to the reader. This is where you get to exercise your artistic talents.

Poor cartography is a sure way to degrade the real value of an otherwise good survey. On the other hand, good cartography does not necessarily improve an otherwise poor survey.

Assuming that you will apply data-taking techniques and a methodology which yields high quality data, then the planning and underwater efforts are deserving of high quality cartographic techniques. There is much to be considered in this phase, particularly for high grade surveys with much detail on features, and a complete section is devoted to the cartographic process.

## THE PUBLICATION AND COPYRIGHT PHASE

The completion of the cartography phase puts you in the home stretch. With the cartography completed you have already made the decision on the reproduction method, so the remaining tasks are the printing and the execution of the copyright procedure.

The copyright procedure establishes ownership of the map and the right to authorize reproduction and display of the map. Copyright, however, does <u>not</u> restrict the use or application of the information on the map. This subtle but significant point is

generally misunderstood. This point and the applicable copyright laws and procedures are treated in detail in the section on Publication and Copyright.

Now, having walked step by step through each phase or group of tasks, you have traveled completely through the survey process from start to finish. In the following sections we shall concentrate on the specifics within the phases and develop the applications necessary to apply the survey process in its entirety to a real survey project.

# SECTION 6

## THE SURVEY TEAM

### INTRODUCTION

Suffice it to say that underwater cave surveying is not for everyone. Like any other aspect of cave diving, it should be done a little at a time as proficiency is developed gradually, with experience. There are a number of divers in the cave-diving community who have never surveyed a foot of line and who never will. However, those who do survey, and those who would like to, need to take into consideration a few thoughts in assembling a survey team. As pointed out in the prior section, there is much more to the survey process than scuba diving, and the makeup of the survey team will have a bearing on the conduct of the entire process.

The team and how it functions will determine the outcome of the whole project. Team member selection is paramount in safety considerations, of course, but safety is not the only consideration. The individual members should, above all, have common objectives and should be willing to work individually and collectively toward a common goal. No room for superstars here, just a common bond of getting the nitty gritty planning done, getting all the information, crunching all the data, and eventually getting it all down on paper.

A survey team may be just a single individual cave explorer, or it may be made up of a number of individuals or groups who undertake extensive projects and coordinate their efforts with others. Some caves are surveyed by a single buddy team, whereas some of the larger systems are surveyed by groups of smaller teams. In any event, the qualifications needed by the individual members are generally the same. There may be a need, however, to comprise the team of divers with different skills and interests. For example you shouldn't undertake a survey which will require staging or scootering with team members void of staging and scootering experience. Likewise, you may have some team members who get more enjoyment from and are more skilled in the data-taking aspects of the survey, whereas others may get more fun from the cartography. In other words, the team members should complement each other and should encompass all the skills required for the complete project.

### TASK LOADING

In order to survey, the diver takes on tasks beyond those

required simply to dive safely. He is using additional tools, and he typically is concentrating on getting a job done rather than devoting his mental efforts toward navigation and his buddy or buddies. Also, the surveyor generally is using both hands simultaneously in taking and recording data (try filling out a survey slate with one hand). Consequently, he must possess sufficient diving skills and manual dexterity to allow him to accomplish survey tasks, record the data, and dive, meaning controlling buoyancy, propelling without silting, monitoring air, and watching buddy while paying attention and being sensitive to environmental concerns such as flow and depth.

**TEAMWORK**

With the makings of task overload situations continuously present throughout a survey dive, the need for task division and teamwork becomes obvious. Recognition of the need for smooth, efficient teamwork then, leads us to conclude quickly that the dive team members must all be attuned to thorough, detailed planning and have a better than average ability to communicate under water. This latter point usually comes with the experience of many dives with a buddy such that communications become more than a vocabulary of hand signals and slate notes. A well organized and effective survey dive team will have discussed every aspect of every task prior to the dive. Virtually any deviation from plan or obvious difficulty can be communicated efficiently, because the basis of the information to be communicated will have already been established. With experience it soon becomes much like calling football plays. You should know exactly what to do when "23 left" is called because you would have chalk talked "23 left," and that signal is in the game plan.

**COMMUNICATIONS**

Optimally, the dive team members should have had diving experience together, and each member should be proficient as a diver with dexterity enough to dive, to buddy and to survey simultaneously without sacrificing quality. Additionally, the members of the team should be able to communicate effectively and efficiently with a basis of communications that goes well beyond the standard underwater hand signals. Hand signals and error-free communications are treated in more detail in a later section.

**COMMITMENT**

Having touched on a few of the desirable attributes of survey dive team members, the real common denominator, however, should be the mutual objective of accomplishing the task. This involves full recognition of the scope of the effort required to

complete the survey project once it is started. Unless an underwater cave survey is an extremely simple one, these efforts usually extend over many, many dives and often over many, many months or even years.

When Frank and I selected Twin Cave as a survey project, we planned the project through four phases and over two years. As of this writing we have just completed phase two; and, on this project alone, we have logged over 1400 minutes of bottom time placing 27 permanent stations and surveying over 1700 feet of line with a maximum penetration of approximately 1200 feet. Now this project is not represented as typical because we were doing a grade 5 class D survey, and much of this bottom time was accumulated in the recording of detail and in establishing accuracy. Additionally, we were developing and refining procedures for the survey process itself. However, some of the gross numbers are indicative:

- 1700 ft of survey took 1400 minutes of bottom time or a little over a foot per minute!

- 27 survey stations took a little over 50 minutes a station!

For a Grade 5D survey, experience to date indicates that for every minute of survey bottom time, you will spend at least one minute planning, one minute crunching data, one minute drafting and four minutes working the cartography phase. This makes the actual dive time only about 12.5% of the total process! 10% would be a good rule of thumb. But it is a tremendous amount of fun, and all the surface work stimulates continued involvement in the project by all team members between dives.

The point here is that a lot of time is required to complete a survey; that the project can be spaced over weeks, months or even years; that most of the work is not under water; and that the team as a team should be committed to completion.

**EXPERIENCE**

Obviously, experience is a driving factor when it comes to gathering a maximum amount of data. Pioneering cave divers and explorers such as Exley and Skiles, for instance, have surveyed passages well over half a mile on a single dive. These individuals have developed their techniques and procedures such that no motion is wasted, and teamwork is at an absolute peak in efficiency.

You will find that every phase of the survey process becomes more and more effective as you accumulate more and more time with the same team members. Frank and I find that we are at least twice as effective as a team when we survey together as opposed to when we survey with others with whom we have little or no

prior experience. That goes not only for the diving phases but for the planning, drafting and cartography phases as well.

**SUMMARY**

Proper makeup of the survey team is a key ingredient to a successful survey project ... certainly just as important as the techniques used or the special tools that will be employed. The team members each must have good diving dexterity, each must be able to share tasks, each must be able to communicate efficiently and effectively, and each must be committed to the project from start to finish.

The more a survey dive team works together, the more experience is accumulated - both as individuals and as a team. Like any other team effort - take an all star football team for example - the individual members each may be very proficient individuals, but the team cannot function effectively without practice ... as a team. And there is a genuine sense of accomplishment from team building. We commend you to it, and guarantee that it will add enjoyment to your diving.

# SECTION 7

## SPECIAL TOOLS

### INTRODUCTION

Like any other aspect of cave diving, some unique special equipment is required.

The biggest single challenge in underwater cave surveying is getting the maximum amount of data with the highest degree of accuracy and reliability in the minimum amount of time. Techniques and procedures can be developed which optimize the task loading and task flow to speed up the process. However, there is also tremendous opportunity for innovation in the area of special tools, and you undoubtedly will apply your own personalized adaptations of instrumentation.

I shall describe here the tools we use. Some are the result of our creativity and some have been passed on to us. Although people are writing and talking about using sonar techniques for underwater cave survey purposes, the equipment we have experimented with is fun to use but has limited utility and is applicable to a rather narrow range of unique circumstances. In spite of the technology available in today's high tech world, we consider the line, tape, compass and depth gauge as state of the art.

Shown in Figures 7-1 through 7-5 are variations of the basic tools that all underwater surveyors use today.

The four essential tools are the compass for measuring azimuth direction, the depth gauge for measuring depth or height, the knotted line for measuring distances, and the slate for recording data.

### COMPASS

There are many, many makes and models of compasses and depth gauges on the market, and some certainly are more appropriate than others when used as one of the primary instruments in surveying. My suggestion is to select those which suit your purposes best. Some compass features which aid the data taking process are listed below:

- A well damped compass card which allows the arrow to rotate slowly and smoothly. (The compass card is that part of the compass to which the arrow is integral and which rotates seeking

magnetic north.)

- A compass card with minimum space between it and the viewing surface which minimizes parallax error.

- Well defined course markings which facilitate quick, easy reading through a mask.

The majority of underwater compasses used for routine navigation are calibrated in five degree increments, and a great deal of care must be used to obtain a reasonable degree of accuracy. Liquid filled compasses with two degree increments such as those used for backpacking and trail navigation serve even better. The Silva Polaris 7 is such a compass and is sold by Recreational Equipment, Inc. in Seattle, WA.

**DEPTH GAUGE**

There are some depth gauges on the market which provide a substantial degree of granularity between depth scale increments. Recognize that in the survey process you are more interested in the relative depths of floors, ceilings and features than in the absolute depths below the surface of the water. Incremental readings with a high degree of granularity enhance the process considerably. (Two foot markings versus five or ten foot markings, for instance.) Also, you should select a depth gauge which has minimum susceptibility to hysteresis. The hysteretic effect is the lag in the gauge to respond to changing depths. This effect can be minimized somewhat by technique wherein all floor depths are taken, then all ceiling depths are taken versus moving from floor to ceiling, floor to ceiling. You also should use the same gauge for all measurements on a given dive, and each team member's gauge should be referenced to the others' and to the water level at the beginning of each dive. This process assures consistent readings between team members to the maximum extent possible. Whereas the dry cave surveyor can use instrumentation to determine vertical angle, the underwater practitioner is left to calculate vertical angles from distance and depth data. Accurate relative depths, therefore, are important.

**SURVEY SLATE**

The compass and depth gauge are the two instruments involved in every measurement at every station in a survey. Likewise, the slate is used to record all the data from every measurement. Therefore, since these three tools are used simultaneously, we have chosen to combine the three into a multipurpose tool which we dub (for lack of a more innovative term) the survey slate which is shown in Figure 7-1. As you can see in the illustration, a compass, a depth gauge and a bubble level have been mounted on a slate preinscribed for data recording with an

attached pencil. The bubble level serves as a reference when taking azimuth readings to insure higher accuracies. Without a reference to level, it is especially easy under water to take an erroneous azimuth reading from a tilted compass. You will find that the bubble level reference reduces azimuth data error rate very substantially.

Fabrication of a survey slate is simple. A slate cut to a size you prefer, a depth gauge, a compass, and a pencil and line are all the parts that are required. The pencil holder shown here is a standard nylon wire tie. One caution, though, on the mounting hardware - it must be non-magnetic .... either stainless steel or brass. If in doubt, pass a nut and or bolt near the compass. If the compass card is deflected at all, the hardware has ferrous qualities and should not be used. As for the pencil, I prefer one which has a continuous lead (although I always carry a spare in my pouch). Pencil sharpeners are typically scarce in caves and are usually found only in the form of a dive knife. Your preference, but I also have an eraser on my console slate pencil which is useful from time to time.

There are four particular points that need to be considered in mounting the instruments:

1. The compass lubber line must be exactly parallel with the long edge of the slate because the edge is held against or parallel to the survey line to obtain a compass heading.

2. None of the instruments on the slate should be interactive. That is to say, the depth gauge, like the mounting hardware, should not have any magnetic qualities which would cause any deflection of the compass needle.

3. The instruments should be arranged for easy reading, on the left side of the slate for a right handed diver or the right side of the slate for a left handed diver. This arrangement facilitates easier writing on the data side of the slate versus having to write over the instrumentation.

4. The bubble level, available at any recreational vehicle supply store, should be mounted such that it can be viewed simultaneously with the compass. This proximity eliminates the need for eye motion and enhances the diver's ability to note the exact compass heading when the slate is level. This refinement adds substantially to the accuracy of compass readings and eliminates a major source of errors.

The larger survey slate shown in Figure 7-1 is 9 inches X 11 inches and may be too cumbersome in some instances. An abbreviated and smaller version is also shown in Figure 7-1 which is merely a compass mounted on a 5 inch X 7 inch slate. The advantage of the smaller version, of course, is stowage. It can be stowed in a pouch, a pocket or even tucked under the edge of a wet suit jacket or shorty leg. Using the mini slate, however,

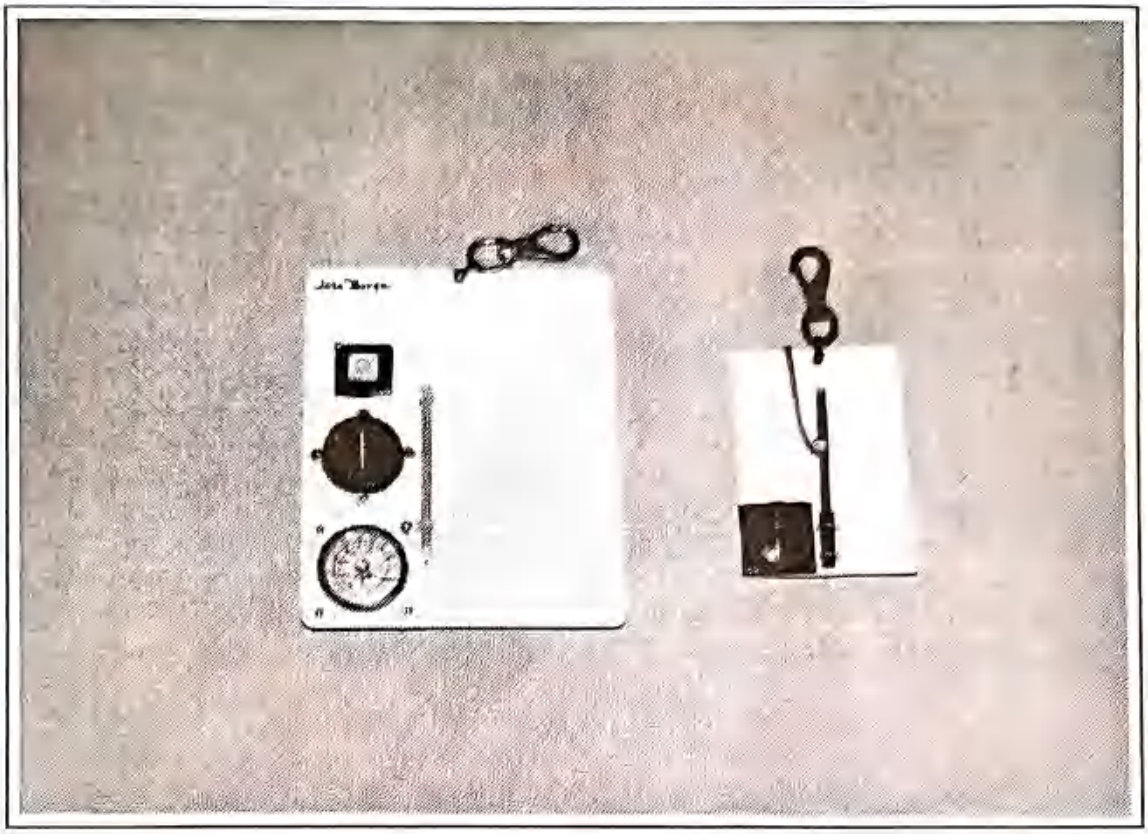


Fig. 7-1 Survey Slates

would require the use of the diver's depth gauge as the survey instrument which may or may not be desirable. The larger slate is inherently more accurate because of the longer straight edge used for reference to the survey line. The smaller slate is easier to use in close quarters and when taking measurements in high flow or cross current conditions.

**KNOTTED LINE**

Figure 7-2 shows a line reel loaded with knotted line. Over the past several years it has become more of an accepted practice for initial cave explorers to lay in new line which is knotted at 10 foot intervals. Hopefully, this practice will become universal as it certainly makes follow-on surveys much easier. Today, however, there are many, many unsurveyed caves with permanent lines in place which have knots only at the tie points. Hopefully, the divers who lay new line or replace older lines will install knotted permanent line which provides distance information to the diver. Generally, however, permanent lines are not suitable for surveying since the surveyor needs straight lines, point to point. A line which hugs the wall around a curve is of little or no value for survey purposes. More on line laying technique in the next section.

In any event the knotted line, 10 foot intervals, is the

Fig. 7-2 Knotted Line Reel & Tape

common tool today for measuring distances on long surveys or surveys which have no requirements to meet the accuracies of grade 3 or better. Braided nylon line which is the "standard" underwater cave guide line has a stretch coefficient of up to 20% although care and attention to this detail by the diver can hold repeatability of measurements to within perhaps 3% or so. Even with great care and attention to the "stretch factor", however, grade 3 or higher is virtually impossible to attain without at least some tape verification.

The line reel shown in Fig. 7-2 is a typical line reel. Some surveyors prefer to make some unique modifications to their reels which enable the diver to cut line conveniently and to eliminate the need for a third or fourth hand. One such modification is the installation of an Exacto knife blade in a slot in the reel handle. A slot is used to protect the hand from the blade yet allows the line to be cut by passing it into the slot across the slanted blade. Another such modification is the installation of a friction clamp to hold the line end to the reel after it has been cut. This precludes the loose end of the line on the reel from coming unwound and creating another type of tangle problem while the diver's hands are occupied tieing the end of the line he just cut.

Yet another application of ingenuity by one surveyor I know is the installation of a line-length counter on the line reel which actually counts the feet of line as it is paid out from the

reel. This adaptation of a hardware store device can eliminate any error in counting knots and can save verification time.

## TAPE MEASURE

A surveyors tape is certainly a required special tool for surveys of grade 3 or higher. You may be assured also that taped measurements are time consuming; they are best done by two divers; and they require error free communications. They are, however, the most accurate and reliable.

We have tried several different types of tapes and found that a standard fiberglass 100 foot enclosed reel builders tape is very practical. Where the closed reel tape can foul and bind in a dry muddy cave, the one advantage in an underwater cave is that the tape simply stays washed and clean. The one shown in Figure 7-2 has proven very reliable and has demonstrated the following advantages:

1. Low cost - a good quality, 100 ft fiberglass enclosed builders tape can be bought for about $25 - $30.

2. Zero stretch coefficient.

3. Compact and easy to stow. Is even a fairly "clean" dangly.

4. Can be clipped off or tied to a tie point by the tape itself.

5. Flows freely in water and does not tangle easily. Will untwist itself readily upon retrieval.

You are not likely to find a tape much more suitable than the type shown here. However, some surveyors do well with a standard open frame surveyor's tape with a large retrieve handle which has a decided advantage insofar as retrieval speed is concerned. Also, some surveyors use a tubular fiberglass tape which seems to serve them equally well.

## SURVEY STATION MARKERS

Next in the bag of survey goodies is an ample supply of station markers. Three types of markers are shown in Figure 7-3, and all of these are inexpensive and are easily fabricated from standard slate material.

The first is simply a modified directional arrow that is placed on a line and sometimes left as a permanent reference. The points of a standard line arrow are cut off, and the appropriate data are written on it with a soft pencil. The arrow then still

serves as a directional indicator but is quickly identified as a survey station marker by its unique shape. Next and more common to our usage is a small rectangular slate approximately 1 inch X 3 inches attached to a tie point by nylon line. This is the method we prefer and which we use as permanent station markers- left in the cave for future reference, for verification, or for use by future surveyors. By leaving these little identifiers in the cave and by noting their exact locations on the map, we are able to give the reader an added dimension of information, and we strongly recommend their use in this fashion. The third marker you should always use is shown also in Figure 7-3 and is actually a notice of sort that a cave is being surveyed. Such notice should be left in an obvious location, conspicuous to any diver entering, during the entire duration of the survey process- days, weeks, months or years. We frequently leave extra reels, tapes, hammers, hardware and even extra tanks in a cave during a survey. A sign of this sort at the entrance serves notice that:

1. Extra lines may be in the cave

2. The survey team may have left items in the cave and that it is <u>not</u> "Finders keepers, Loosers Weepers."

To date the only things we have lost have been due to our own forgetfulness or negligence - <u>not</u> because some other cave diver made off with a newly found goodie.

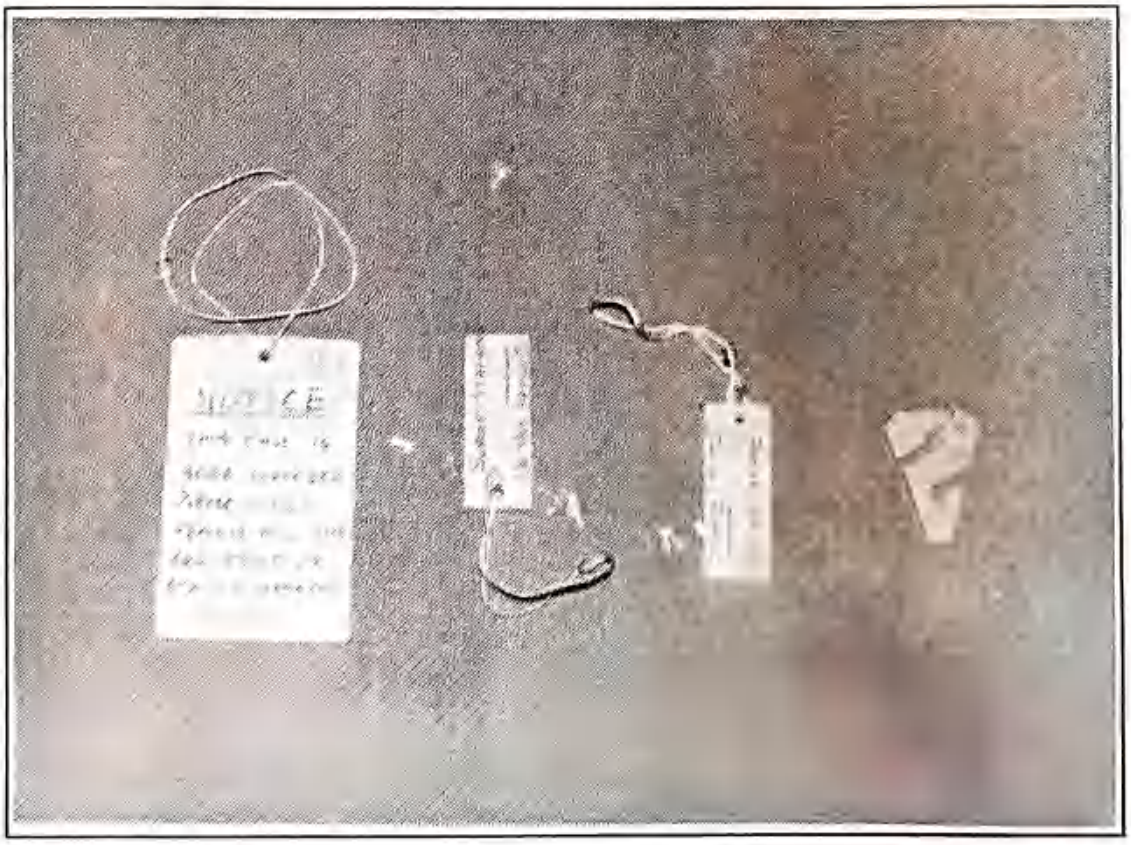


**Fig. 7-3 Survey Station Markers**

**FASTENERS**

Of course there must be a method of attaching the survey markers permanently, and there are numerous techniques available. Keep in mind that many caves are very fragile and utmost care should be taken to avoid damaging the cave. It is impossible to survey an underwater cave without installing a survey line which must be fastened at various points in the cave. However, the surveyor should also be ever mindful of conservation and preservation and should use care and discretion when selecting survey station points. The most desirable and the least damaging to the cave is to tie the marker to a small knob of limestone- if one can be located at the appropriate point and if it is substantial enough to support the line tension. Frequently this is not the case, and some other method must be employed. We now use 60 penny galvanized spikes which, if driven in properly, can be employed quickly with minimal damage to the cave and can be removed if necessary. The 60 penny spikes serve well in much of the karst we have surveyed ranging from very soft to fairly hard limestone. To drive and to remove these spikes a carpenter's claw hammer with nearly straight claws is recommended. The claws make spike removal quick and easy and can double as a rock hammer for sample collecting on scientific surveys. Care should always be exercised to preserve every aspect of the cave.

In frequent instances, harder substances are encountered and

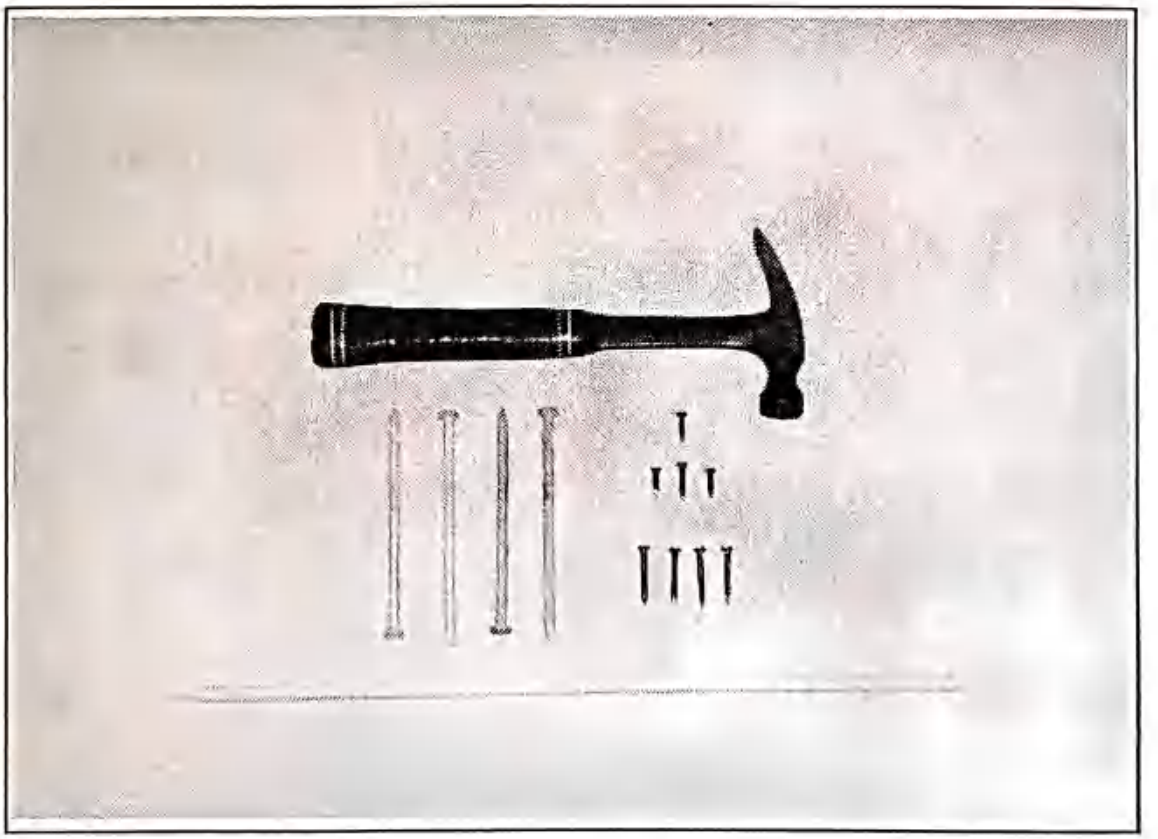


Fig. 7-4 Permanent Fasteners

concrete nails, which come in several sizes, serve equally well and can be installed quickly and easily with a few sharp blows of the trusty claw hammer.

These fasteners are illustrated in Figure 7-4.

## SURVEYOR'S HELMET

Last but not least of the special tools you will need is the helmet. It is not so much for safety, though it does protect the head, as it is to serve as a light holder. As mentioned before, the survey process frequently requires the use of both hands simultaneously (driving spikes, taking measurements and recording data). Light handling, as an additional task, can stress and impair the efficiency of even the most proficient diver with excellent dexterity. The helmet shown in Fig. 7-5 is a personal preference and is a modified bicycle helmet. As you can see, PVC pipe fittings, properly located, serve as excellent light holders. A standard 1/2 inch plug is bolted and glued to the helmet, and a saddle coupling is screwed on to the threaded base of the plug. The saddle can be adjusted to fit a variety of light head handle sizes simply by heating it with a propane torch and bending it to the proper size. Its resiliency returns after it cools. As shown here, the top saddle has been tailored to fit a Diverite SB-12 light head and the forward saddle tailored to fit an Underwater Kinetics QXL-3.

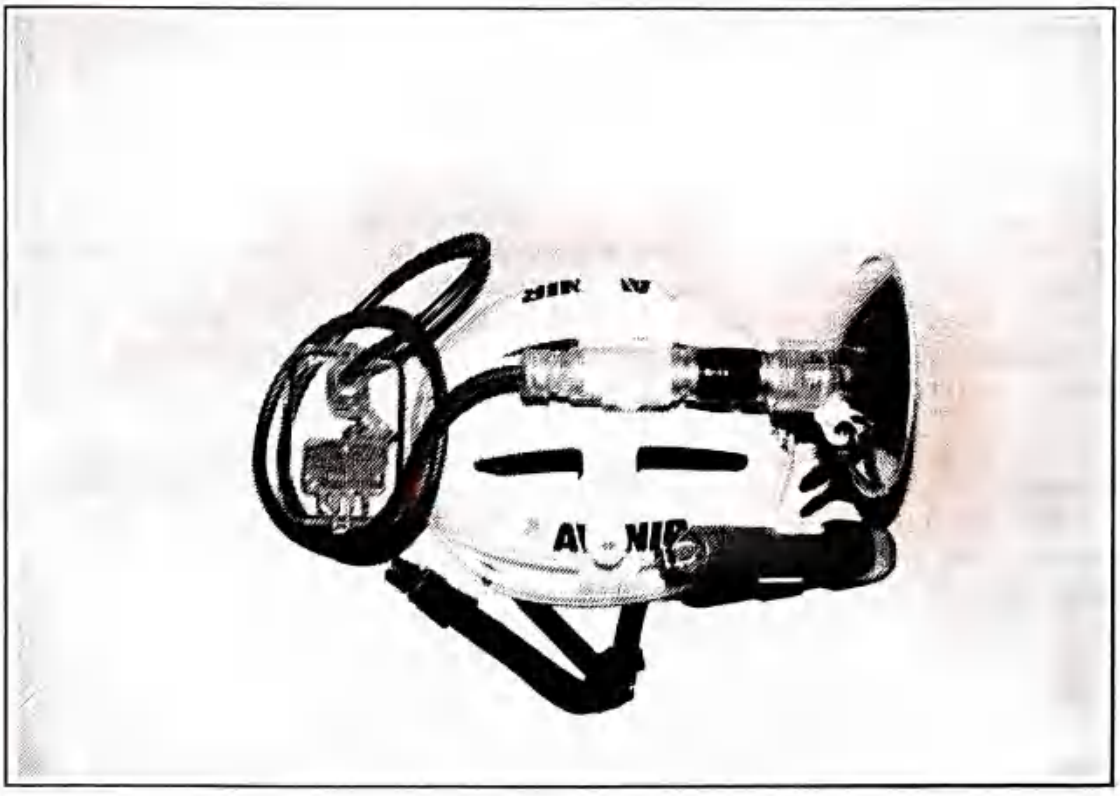


Fig. 7-5 Surveyor's Helmet

Different size saddles then can be interchanged to accommodate most of the popular light heads. Positioning of different bases can be employed also for different functions. Note the base on the right forward area of this helmet. It has been positioned to hold a QXL-3 saddle which shines exactly on the lens and shutter speed/film advance lever of my Nikonos V, since the backscatter from my primary light head is inadequate to illuminate the numbers I need to read on my camera through my bifocal mask lens.

Most bicycle helmets come with a styrofoam lining for protection which adds buoyancy under water. Therefore, some styrofoam removal to suit your personal need is in order. There are numerous types of helmets that can be modified and tailored to meet your unique requirements. You need, however, to select one that is substantial enough to support the light holders. I am most satisfied with the version illustrated here, but I am sure your own creativity and ingenuity can serve you well. One thing for sure, though .... the underwater cave surveyor will be hard pressed to avoid task overloading without a head-mounted light holder of some sort. And finally, configuration of the light holders will be a matter of personal preference.

**LINE KNOTTING TECHNIQUES**

Use of knotted line as a distance measuring tool was cited earlier, so an explanation of some knotting methods is in order. Three techniques are described below.

1. Two people sit facing each other at marks on the floor 10 feet apart. One person holds the spool of nylon line and the other holds the reel. The line is threaded on the reel by the reel man, and the reel is positioned over the mark. The spool man ties an overhand knot in the line exactly over his 10 foot mark. The reel man then takes up line to the knot and the process is repeated. The error here is cumulative or additive, meaning that an error on any given increment is added to any subsequent errors and can accumulate into larger errors. Two people are required.

2. Lay out a 100 foot tape on the ground, street or sidewalk. Load a line reel with the nylon line of your choice ... #30 to #36 is adequate. Secure both the end of the tape and the end of the line at the same point. Walk the length of the tape, paying out line from the reel and tying a simple overhand knot in the line, with the reel, every 10 feet. The "stretch factor" has to be watched carefully using this technique, and probability of error increases as you pay out more and more line. Errors are not cumulative, however, since each knot is tied to a cumulative distance on the tape. (i.e. 75 feet is 75 feet regardless of any error that might have been made between 0 and 75.) One person can do the job.

3. Drive two large nails 10 feet apart into the top of a work bench or other convenient surface, or mount two upright boards 10 feet apart with a vertical slot in each just the width of the line thickness. Loop the end of the line over one nail, or slip the line with a knot on it down one slot. Pay out the line to the other nail or slotted board. Tie another knot, and loop the line around the nail, or drop it in the slot. Repeat this process. The error in this process is inherently cumulative, but you can see all the knots, and one person can do the job.

**SUMMARY**

The tools shown and discussed here are the basic ones and are most frequently employed. You may find need to devise something unique to do a particular task. For example, the survey of vertical passages or very steep inclines can generally be done by plumbing the line using the reel as the plumb weight and positioning survey stations directly below one another. This is procedural; however, you may have need to measure angles and therefore may want to devise a tool to serve as a clinometer. In other words, as you take on survey tasks more unique and further removed from the norm, you may find the need to design more special tools to do special jobs. Such is always the case in cave diving .... the more adventuresome are continually developing and refining methods and procedures as well as equipment and tools.

For the most part, however, the tools described here as well as the techniques described later will serve you well for the large majority - perhaps all - of the survey tasks you are likely to perform.

# SECTION 8

## TECHNIQUES AND METHODOLOGY

### INTRODUCTION

Frank and I have developed a number of techniques and methods which are the ways we prefer to get things done. Please recognize that you and your dive buddies may prefer to do things differently, and that's fine. Underwater cave surveying involves the taking of numerous measurements and the recording of a lot of data while working within very finite limits .... your air supply. Obviously, one should strive for efficiency and accuracy and that means getting the maximum amount of data in the minimum amount of time with the least amount of effort. This section treats the following techniques to enable you to do just that:

| | | | |
|---|---|---|---|
| Dive Planning | Survey Dives | Tie Points | Vertical Survey |
| Large Chambers | Radials | Hand Signals | Data Prep |
| Sketching | Long Passages | Stick Maps | Higher Grade Maps |
| Compass Errors | | | Compass Reading |

Based on our experiences and our very deliberate efforts to optimize, we now approach a survey project, or even a single dive, in an organized, thought-through manner. We determine exactly who will do what, how, when and with whom long before we even begin to assemble scuba gear. Let's walk through these techniques, one at a time. You may prefer to do it differently; however, unless you have already refined your own techniques, these procedures will be a good starting point.

### DIVE PLANNING

Once you have selected a cave or cavern to survey and have determined the grade level to which you intend to survey, you should "scope" the task. By that I mean you should lay out a dive plan simply to look at what you are going to survey and go down a check list of considerations, such as:

- Depth and flow and therefore bottom times on subsequent dives. Here determine how you will dive - singles, doubles, staging, need for extra tanks for decompression, need for oxygen, light burn times.

- Cave environment, flow, silt, complexity.

- Availability of natural tie points. If it is obvious that a lot of knobs and points are available as tie points for

station markers, you know you must have precut station marker ties or a jump reel supply of tie line. If tie points are not readily available, check out the hardness or softness of the points where you need to attach station markers. This determines what types of fasteners you will use - spikes, concrete nails, long pointed dowels or other types. Typically we will use some of each.

- The best method of survey. Single base line, traverse, circumline, radial, etc.

After scoping the tasks, then assemble the appropriate gear for the type of diving you will do. Fabricate and assemble the special tools you plan to use. Cut and pretie a supply of station markers, gather a supply of fasteners, and assemble several sketch slates if a great deal of sketching will be required.

When the tools are determined and you have discussed your plan of attack, then plan the first dive, task by task. As an example, let's say that you plan to start a survey project in the front end of a cave which has a large room or passage. You would lay out a dive plan where diver 1 would handle the reel and record all distance measurements; diver 2 would place all station markers and take all tape measurements. Diver 1 would take and record all depths, and diver 2 would take and record all azimuths except on radials where diver 1 would hold one end of the tape and take azimuth while diver 2 would handle the tape reel and take distance. Very simply, the tasks are divided into equal individual loads and you team as necessary. For example, you both know ahead of time that when diver 2 gives diver 1 the end of the tape, diver 2 will swim the tape reel out to the station to be measured and note the measurement while diver 1 takes the azimuth. He knows that diver 2 will hand signal three numbers which he is to verify and then record while diver 2 takes up the tape or swims it to another station. You should always plan ahead who will do what, how and when.

With apriori knowledge of depth and flow you can fairly well determine what your bottom time will be and how much you can get done. At first, you will undoubtedly schedule far more than you can possibly accomplish. This over expectation of accomplishment is very typical, and you will probably find that you learn this lesson several times before you finally adjust to the realities of the inefficiencies of underwater surveying. Like everything else, however, practice does not make you perfect, but it certainly improves your efficiency. If you are looking into a 60 minute working bottom time, for example, you might plan to lay a complete circumline around this large entrance room with five to ten stations depending on cave geometry and dimensions and take DAD (Depth, Azimuth and Distance) on all legs. Laying the circumline would probably not take 60 minutes, so you would plan also then to take radials until you reach air limit for efficient time utilization.

With this plan in mind you would then lay out your survey slates in DAD format which is described in more detail later, and write each task, numbered, on the slate. You would then be ready to dive.

## SURVEY DIVING

We have added a "dangly" check to our S drill or safety check at the start of each dive and suggest that you do also. You should check all your lights and breathe on all regulators and do a leak check on each diver. You also should check each diver for proper positioning and stowage of tools. Remember, you could be carrying a station marker tie line reel, a hammer, spikes and other fasteners, a survey slate, a tape reel and, perhaps, even additional sketch slates. Particular attention should be paid to this predive check since the surveyor is a prime candidate for dangly dilemma.

## TIE POINTS AND LINE LAYING

You would then enter the cave with one of you on the reel and the other tending line. Proceed slowly visually examining and exploring the features of the cave for good tie point locations. The criteria for tie point/station marker location goes as follows. Each and every tie point, if possible should:

- Have sufficient head room above it for the diver to be able to hold a survey slate in position against the line and read the instruments from directly above. The compass can be read **only from above**. It is frequently tempting to tie off to a "nice looking" tie point without giving the overhead proper consideration. You will probably make this mistake a time or two before you complete even your first survey.

- Be in line with the prior station with the line free from touching any other object. If you must lay the line across the flow, avoid the current. Right on the floor is sometimes a good choice in a cross-flow situation. Even slight flows will bend an orthogonal or broadside line causing it to curve and to introduce azimuth error.

- Be at or near the same depth as the prior station. Accurate compass readings are difficult to obtain from slanted line. If the cave slants downward, it is best to run the line point to point near horizontal and drop the line vertically to another station directly below. See Figure 8-1.

- Be of a reasonable distance from the prior station to serve as the base reference for outer wall sketching .... ten to twenty five feet if the outer wall is complex, longer if the structure of the outer wall is simple. Shorter in high flow, longer in low flow. See Figure 8-2.

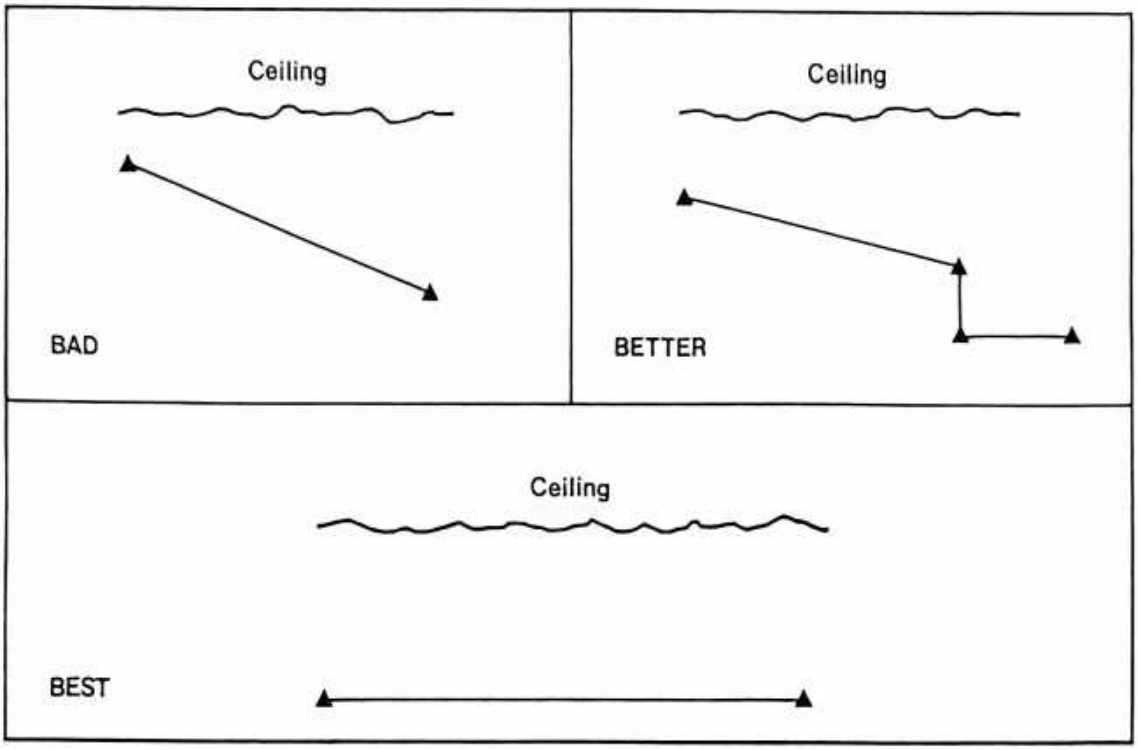



Fig. 8-1 Station Locations - Vertical Considerations

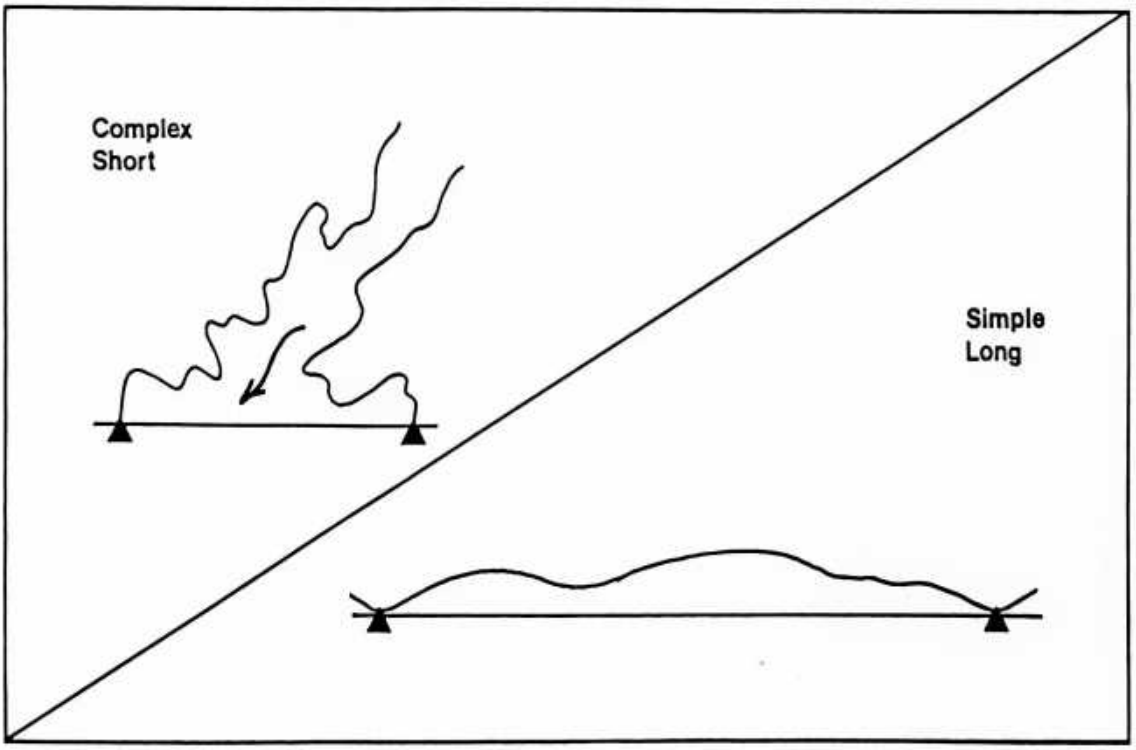



Fig. 8-2 Station Locations - Sketch and Flow Considerations

- Be substantial enough to withstand the tension of a tight line or be able to accept a fastener (spike, nail or dowel). Use care to select a tie point that is structurally sound, and avoid tieing off to any fragile feature. You are there to survey the cave, not to damage it.

## VERTICAL SURVEY

Positioning a survey station directly below another is quite simple in anything other than a high flow environment. Simply tie off at the upper station, run out sufficient line from the reel, lock the reel and drop it using the weight of the reel as a plumb bob. We have used this technique in vertical passages as high as fifty feet with excellent results. See Fig. 8-3.

Even if a convenient station is not directly below another station, you can "fix" the lower station from a point directly below. As seen in Figure 8-3, station 14A is ten feet directly below station 14, and station 14B is five feet from phantom station 14A at the same depth and at an azimuth of 305 degrees. This technique is easy to execute and certainly much more accurate than trying to get an azimuth reading on a line from station 14 to station 14B. Can you imagine how difficult it would be to try to measure the 305 degree azimuth on a line slanted downward at 63 degrees?

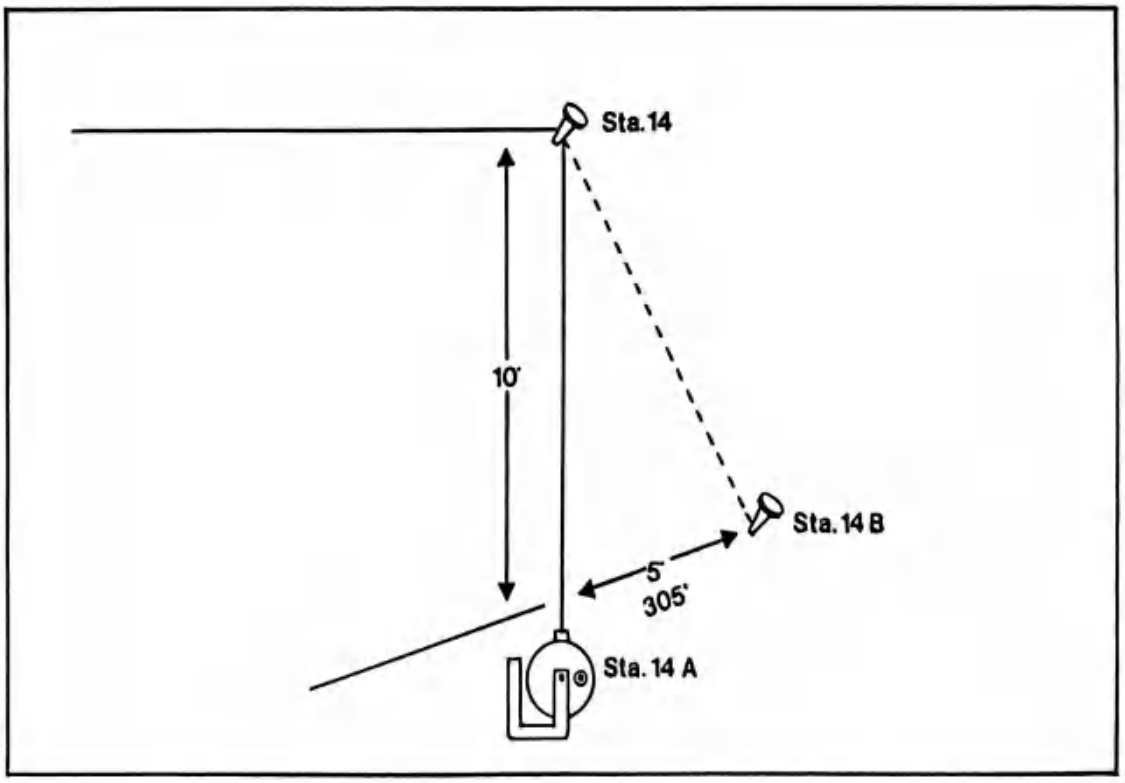



Fig. 8-3 Plumbing the Line with the Reel

LARGE CHAMBERS

As you proceed around the chamber selecting tie points, the lead diver signals with his light the point he has selected for the next station. If the other agrees, he does nothing; if he prefers a different point, he signals with his light. The lead diver considers the alternate tie point and selects one. As the lead diver begins to tie off, the other pulls the line tight and sights to the prior station to assure a point-to-point leg. The lead diver then finishes the tie off and proceeds to select the next station while the other diver assigns a number and places a station marker by one of the methods previously discussed. We always start a survey with station 00 and number sequentially in the order of placement. Any logical sequence will do.

Working your way around the room laying line around the outer limits and placing station markers, you will actually close a loop around the circumference and tie off again at station 00. This line is referred to as the circumline.

After laying in the circumline, you then move into one of two procedures to begin taking and recording data. At this point we inject what we call proximity planning. If the environment is such that we can always see each other and separation distance would be acceptable, we will proceed in opposite directions around the circumline with each of us recording DAD unless taped measurements are required. Tape measurements are a two-man task. On the other hand if this technique would cause us to be visually separated for any reason - silt or otherwise - or if the distances are such that our separation would be beyond either of our comfort levels, we proceed differently. In this case one of us would lead taking the end of the tape. He would proceed to the next station and record depth at station, floor and ceiling. The other would record azimuth and distance.

Although you don't have the luxury of duplicate data in the latter method as you do in the former, the latter method provides for all depths with the same depth gauge, and all azimuth readings from the same compass. Additionally, the tape serves as a buddy line in poor visibility conditions or longer distances and adds an element of safety.

**RADIALS**

After recording DAD on all legs of the circumline, take as many radials as time permits to conclude this dive. Having made the round of the circumline and returning to station 00, one of us would give the loose end of the tape to the other and swim to station 02 or 03, or 04 depending on the shape of the circumline. One holds the end of the tape at 00; the other pulls tight and holds. One takes an azimuth reading on the tape edge and the other notes the distance. As mentioned before, the diver with the end of the tape records the radial data since the other

needs both hands to handle the tape reel.

## HAND SIGNALS

At this point you must communicate the distance measurement, error free. We do it like this.

First, always use the standard hand signals shown in Figure 8-4. Here again I cannot over emphasize the importance of using these signals correctly. Regardless of the hand or the diver's position (upright, sideways or upside down) the palm of the hand faces out on numbers 1 through 5, whereas the palm faces in on numbers 6 through 9. Zero is zero regardless of palm position. Also, irrespective of the data being communicated, we always transmit three numbers be it distance, azimuth, time or air. If the numbers are less than three digits, the first number is zero. Since our tape is 100 feet long, we never have need to transmit more than three figures. Likewise, always transmitting three figures serves as a verification that the message is complete. For example, 9.7 feet would be 097; 65 degrees would be 065. One diver signals 0; the other signals 0. One diver signals 9; the other signals 9. One diver signals 7; the other signals 7. The other then records 097 and signals 097. This is confirmed with "OK."

Since we adopted this method of communicating and verifying, we have not miscommunicated once. As you develop and refine your own team procedures, you may wish to develop your own verification methods.

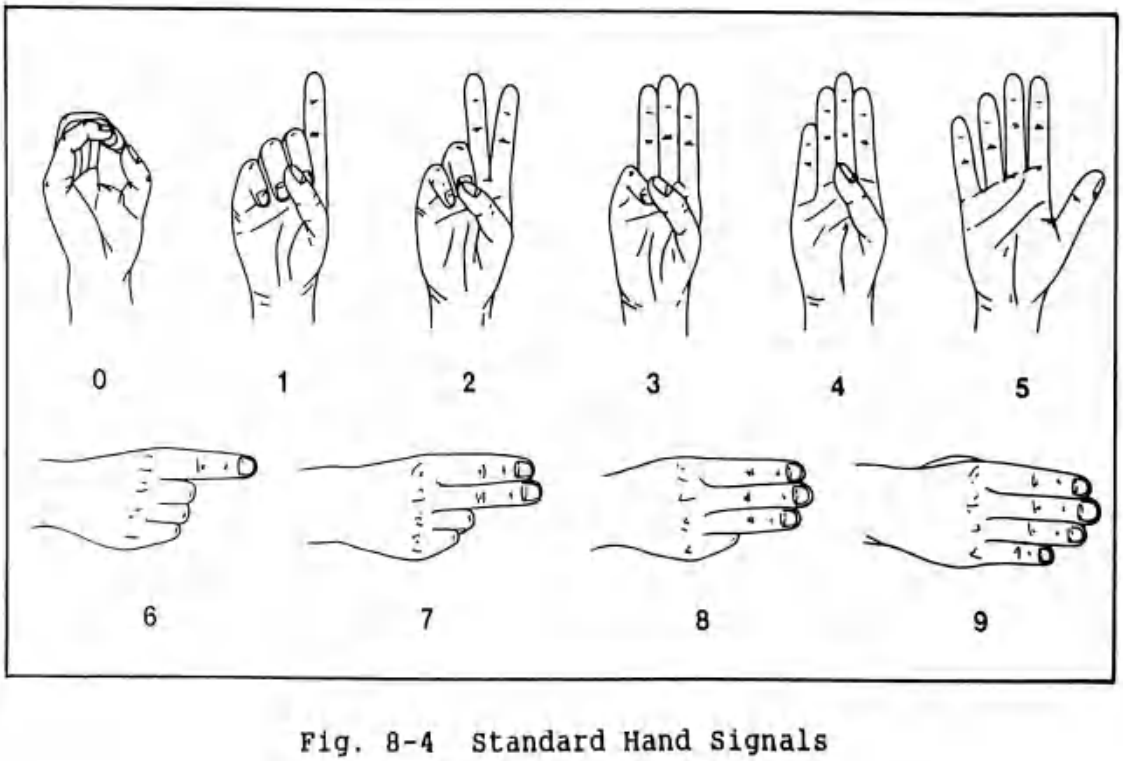



Fig. 8-4 Standard Hand Signals

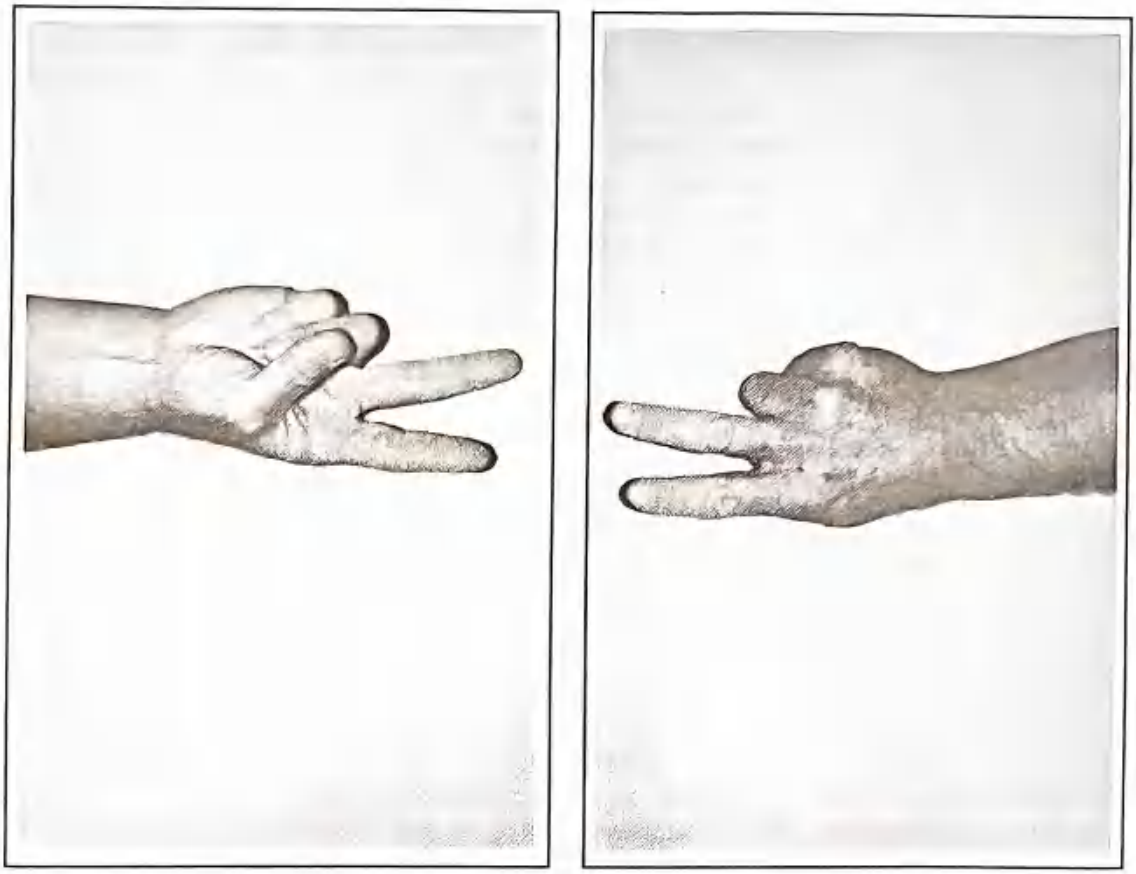


Fig. 8-5 Proper Hand Signals #2 and #7

You may feel that this is going overboard on confirmation and takes too much time. Experience has shown that you will be saving time. Without verification, you stand an excellent chance of recording a 2 for a 7 or a 3 for an 8, etc. It is a real defeat to have to reschedule a verification dive because numbers recorded are inconsistent or erroneous as a result of miscommunications.

**DATA PREP**

At the conclusion of this dive you would have recorded DAD on all circumline legs and several radials. As soon as possible thereafter, preferably right at the dive site, you should clean up this data and record it in your permanent note book. If a repetitive dive is planned, you will want to process the data and lay out a line plot - to scale - on quadrille. Here you will see any errors, and the results will be a line plot loop closed to within acceptable tolerance or a line plot loop out of tolerance. More than likely the latter. The need for verification then becomes obvious, and you may or may not be able to reconcile any errors without additional bottom time depending on the radial and diagonal data you have taken.

After resolving errors and closing the circumline loop on

paper, transfer this loop drawing - to scale - to your survey or sketch slates. A slate with ruled measurements down one side is an excellent aid for this step. Then using the line plot as a base line, determine what additional data is needed. If it is verification or more radials, use the techniques previously described. If you are ready to start sketching outer walls and features, plan the next dive accordingly. You may or may not have picked up the line. If you did, you can relay it, since you should have placed permanent station markers on the prior dive(s).

**SKETCHING**

The technique for sketching outer walls and features or circumsketching, as it is called, is fairly straight forward, but here again you should do some proximity planning. If you need to stay together, divide the tasks so one diver will sketch the outer wall beyond 00 - 01 while the other does the adjacent leg 01 - 02, and so on. If features are extremely complex, you might both do it so you can compare and verify. Probably the most important point here is to emphasize that the person sketching walls, features, profiles or cross sections should do so from a position normal to the viewer. For example, a bottom feature (a boulder for instance) should be sketched from above so the most accurate representation can be incorporated into the map

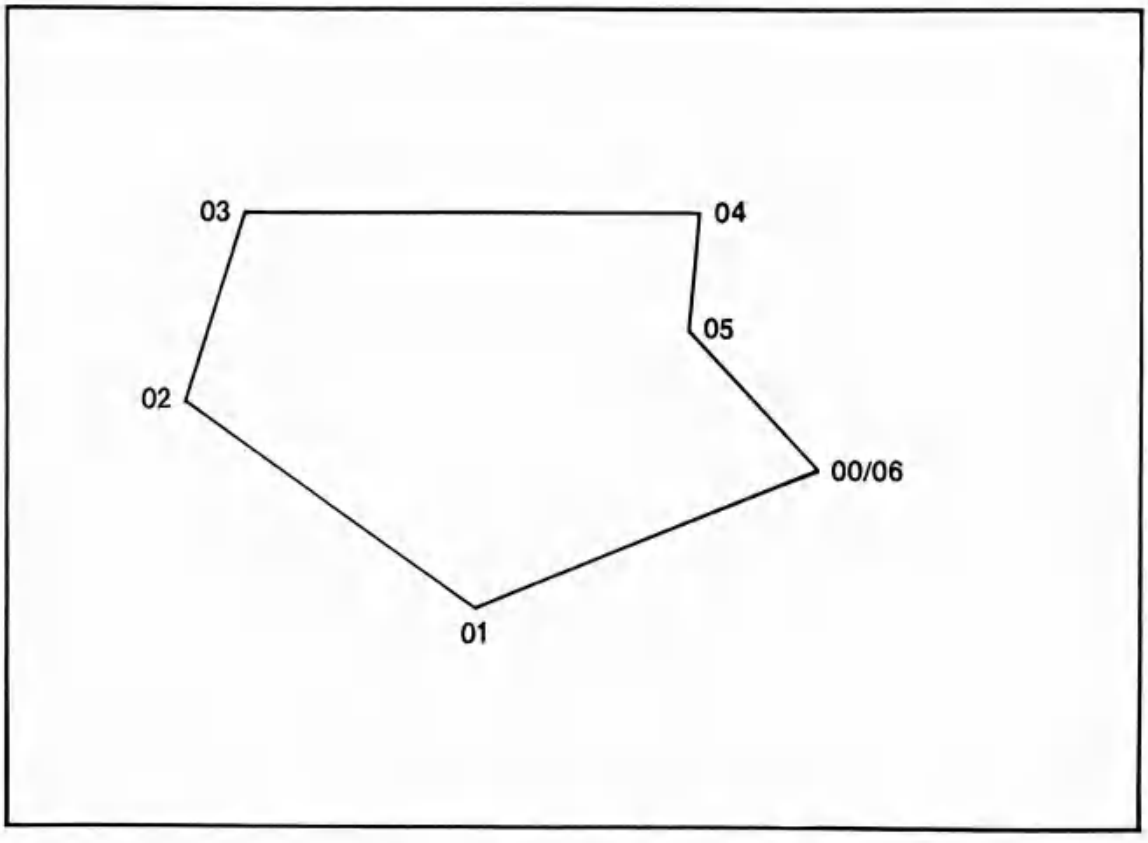



Fig. 8-6 Line Plot

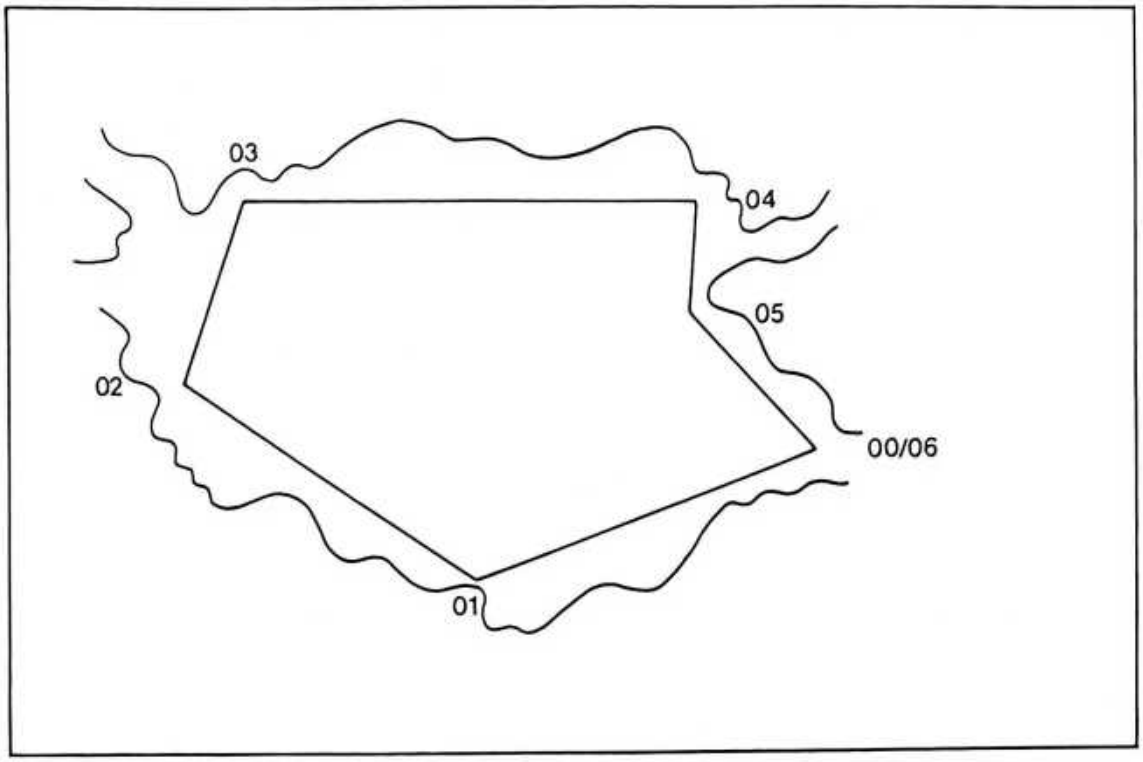



Fig. 8-7 Circumsketch

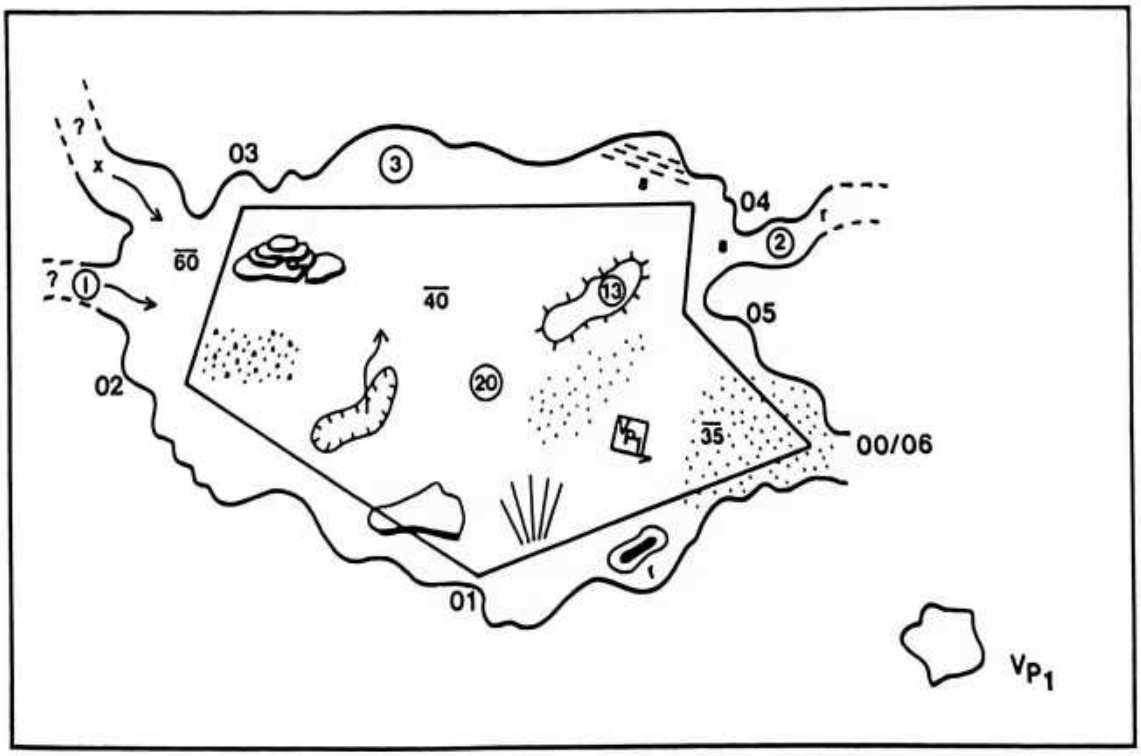



Fig. 8-8 Features

and communicated to the reader. You should note on the map the viewpoint or Vp from which any significant observation and sketch is made - an exit for example - so the reader can know exactly what he should see from a particular point in the cave and be able to recognize it.

You need also to keep in mind that circumsketching is sketching the outer limits of the cave and not just the near wall to the exclusion of low-ceiling chambers. This is a common error.

We have been working on methods to optimize this process with photographic techniques, but a lot of trial and error is in front of us yet. Clearly this is an area where video techniques can be developed which not only would enhance accuracy, but would save a tremendous amount of underwater time. Perhaps you will see the results of these efforts and other advanced techniques in the sequel to this book.

The procedures described here result in slate drawings as depicted in Figures 8-6, 8-7 and 8-8 where Figure 8-6 shows a hypothetical closed loop line plot; Figure 8-7 shows outer wall or circumsketching added, and Figure 8-8 shows some additional data added as features and cross sectional data are sketched in. The complexity of the outer walls and the degree of detail you wish to include in the map, of course, determine the bottom time and number of dives required. You probably will prefer to keep adding sketch data to the same slate as you develop more and more detail.

A point of consideration here is the classification of survey you are taking. You will recall in the BCRA classifications of survey detail and features that:

Class A is based on memory.
Class B is estimated and recorded in the cave.
Class C is measured at survey stations.
Class D is measured at stations and other locations.

The techniques outlined up to this point deal principally with a circumline around a large room with procedures which allow you to develop accuracies up to Grade 5, and surveying to Grade 5 accuracies is time consuming. But what if you don't have that much time and feel that far less accuracy is required? Certainly there are other methods, one of which would be an open loop radial method. This method would entail taking DAD on radials from 00 to all survey stations you can lay in point to point. Referring to Figure 8-6 this would be to stations 01, 02, 03 and 05 with perhaps one from 01 to 04. A very good representation of a circumline plot can then be obtained but grade 5 accuracy cannot be claimed without verification. Also, outer wall, detail and feature sketching is much more difficult to obtain without a circumline in place to serve as a base line for reference and measurements as sketching is being done.

## LONG PASSAGES

So much for large chambers. What about long passages? Generally, these are more easily accomplished unless tight restrictions or unusually difficult passages are involved. Since restrictions, very high flow, and very difficult passages have to be approached as unique with specific techniques required, only long, readily negotiable passages are treated here.

Other than techniques already discussed, there are only a few variations which apply to long passages. You should keep these points in mind as you plan for these types of dives.

- Survey stations must be point to point.
- Long, simple side wall passages allow longer legs.
- Curvy or complex wall passages require the use of shorter legs.
- Proximity planning becomes more important as larger separations and deeper penetrations become more probable.

## STICK MAPS

First, let's treat a stick map survey which typically is done by the initial explorers of a cave system and are very, very significant contributions. They generally are done on initial penetrations on newly laid line, and the scenario generally goes as follows. The lead diver pays out line with consideration for the need for point-to-point stations. Rarely are permanent station markers placed. The follow-up diver places line insuring point-to-point tie offs. Of course knotted line must be used. If a higher grade survey is desired, DAD is recorded on penetration as well as on exit. If not, which is typically the case, the divers record DAD and sidewall data on exit with the tasks being divided logically, as we discussed previously, such as all depths being measured with the same depth gauge and all azimuths being taken with the same compass. These types of surveys are nearly always open loop and would be typed at best a high grade 2 or low grade 3 and class A or B. Let me reiterate that a survey grade and classification serves only to advise the map reader of the inherent accuracies of the survey techniques used to develop the map. There are many stick map surveys available, and the cave diving community owes recognition and appreciation to the surveyors who generated them.

## HIGHER GRADE MAPS

If a higher grade survey of long passages is desired, however, more time and different techniques are required, and the

techniques go like this. One diver, of course, leads with the reel paying out knotted line and selecting tie points to the same criteria previously outlined. We feel, based on our experiences, that we can hold our "stretch factor" on knotted line to ± 3%. That is ± 3 feet within a hundred. And that's pushing it taking lots of care! If we want to be within grade 3 tolerances of ± 50 cm or 1 2/3 feet, then we must limit each leg to no more than 54 feet. By holding our stretch factor to 3% then our error on a given leg would be within .03 X 54 or 1.62 feet. As a practical matter we typically have some legs slightly more and some slightly less than 50 feet and then sample by tape for verification. The amount of sample verification is directly related to your confidence factor of accuracy. For example, if you did 1,000 feet of passage with twenty stations averaging fifty feet per leg and tape verified five legs or 25%, and the errors were consistently small and random (some +, some -), then you would have a high confidence in your accuracy. If you found you were consistently +1 foot, then you should adjust your data accordingly since stretch errors are cumulative.

A point on proximity planning here. Since Frank and I prefer not to be separated as much as fifty feet even under the best of conditions, I have attached a swivel snap to the end of my tape so it can be clipped to a station marker fastener or tie loop. This negates the need for a diver to hold the end, and we can stay closer together. Separation distances, of course, are personal preferences but should be incorporated into your proximity planning.

As one diver pays out line, the other follows counting knots so that each time you reach a new station you know the distance from the prior station. Place a station marker, tie off, record distance, and record azimuth, depth and sidewall data. Sometimes the following diver also sketches sidewall data as he counts the knots sliding through his fingers. Personally, I prefer this technique since I have real time correlation between distance from last station and any particular sidewall feature.

Using this technique enables you to collect all survey data inbound so that when you turn the dive you have only to exit the cave unless you wish to take reciprocal azimuth readings for better accuracy or to do some additional verification or feature fill-in. In other words, survey in and verify out. Obviously, this is more conservative than simply laying line inbound and needing the extra time to survey out unless you do your air management plan accordingly. Some surveyors have differing views on this point, but personally, I prefer this technique.

In the beginning, however, one should not go overboard on adhering to techniques so long as your basic procedures are sound. Initially, simply concentrate on being conservative and keep your task loading well within your limits. As you gain more and more experience, you will begin to modify your techniques and procedures to optimize for efficiency.

One additional point on measurement technique here. This is particularly useful in measuring cross sectional width in a passage. I know my arm span is 68 inches and finger tip to elbow is 18 inches. If the cross section is anywhere from passable to 12 feet or so, I can judge very accurately the distance from wall to wall, wall to line or wall to finger tip. These built-in yard sticks are very handy also in sketching details and features, the dimensions of a boulder or a dome for instance.

## COMPASS ERRORS

Some more on the finer points of enhancing the accuracy of your data taking.

If you are not familiar with the use of a compass for navigation, you may not be familiar with two variables that influence the directional reading of a compass. The first is referred to as **variation** and is simply the difference between true north and magnetic north. This difference is virtually constant for any given location and does not matter since we generally express all map directions as magnetic versus true. The other variable is called **magnetic deviation** and is the angular error which may be imposed on the compass card by the effects of the surrounding magnetic field caused by the proximity of various metals in your dive gear. Fortunately, most dive gear is aluminum, stainless steel or brass and has little or no magnetic influence. However, you may have some gear which could influence your compass - tools in particular - spikes and hammers for instance. There is a way to develop a deviation table as is done on boats and aircraft, but this gets far too sophisticated for our purposes here. Also, it would be very awkward to implement. It is important, though, to know if your tools do have an effect and either to keep the tools beyond the range of influence or to discard them when using the compass. For example, if I hold my hammer in my hand while taking an azimuth reading with my survey board, my compass card will swing several degrees. Simply tucking the hammer into my harness strap at my waist side removes the magnetic influence.

To check for magnetic deviation, hold your compass near various pieces of your dive gear and watch for a detectable needle swing. If the needle is deflected, rearrange your gear positioning to eliminate this influence. Usually, just a few more inches of separation from the compass will have the desired effect. Be sure to include **all** your hardware in this check including all your lights.

Points such as these are indeed subtle, but one should understand the fundamental capabilities and limitations of his instrumentation if he is to develop techniques for getting the most from the equipment he is using. This understanding of the basics of the instrumentation serves to enforce the logic underlying some of these techniques and procedures - taking all

azimuths with the same compass as a case in point.

## COMPASS READING

Compass positioning error is the most common error in underwater cave surveying.

We adopted long ago a technique of "fixing" one end of the survey slate, holding it with the thumb and forefinger of one hand and rotating it with the other hand to position it parallel to the survey line. It is extremely difficult to "float" unsuspended, unfixed, and hold a survey slate, even a large one, exactly parallel to and not touching or deflecting the survey line. Impossible in flow. It is much easier, faster and more accurate to "fix" your hand and one corner of the slate with one hand. This allows you to hold the survey slate in position and stabilize it with the bubble level long enough for a well damped compass card to swing into place and stabilize so you can take your time and get an accurate reading. See Figure 8-9.

Most underwater compasses are calibrated in 5 degree increments and, therefore, a great deal of care must be taken in order to read the compass to within ± 2.5 degrees for grade 3 and especially to ± 1 degree for grade 5. This is made slightly easier with the use of a compass marked in two degree increments

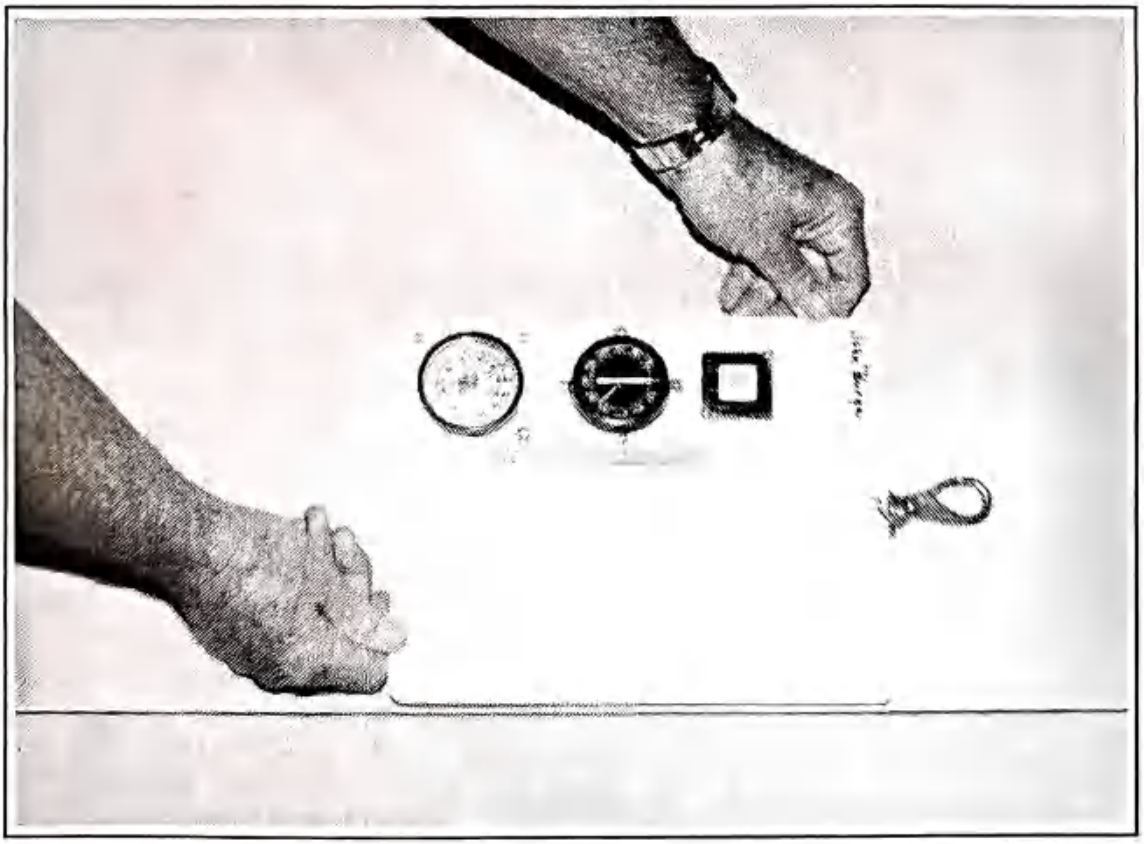


Fig. 8-9 Fixing the Survey Slate

such as the Silva Polaris 7 described in the section on special tools.

If you position the compass accurately, the last error you need to eliminate is parallax which is the error introduced by reading the compass from an angle. Parallax errors are very common simply due to the nature of the environment. However, for the most part, they can be avoided or certainly held to an absolute minimum by taking your time, by using care, and by reading the compass from directly above and looking down the axis of the compass card arrow as shown in Figure 8-10.

We have found time and again that the vast majority of survey errors are developed while trying to hold the survey slate in position and reading the compass. As I pointed out previously, this is indeed the weakest link in the system. We are currently fabricating a line compass which will work on the same basis as a carpenter's line level and is illustrated in Figure 8-11.

The line compass concept is to install a compass which has a compass card that can be locked down once it has been placed into position and has stabilized. Such compasses are available for taking line-of-sight bearings. The line-hang feature will assure accurate and, more importantly, consistent line alignment and will remove one more variable. The lock-down feature will allow the compass to be removed from the line position and held in the

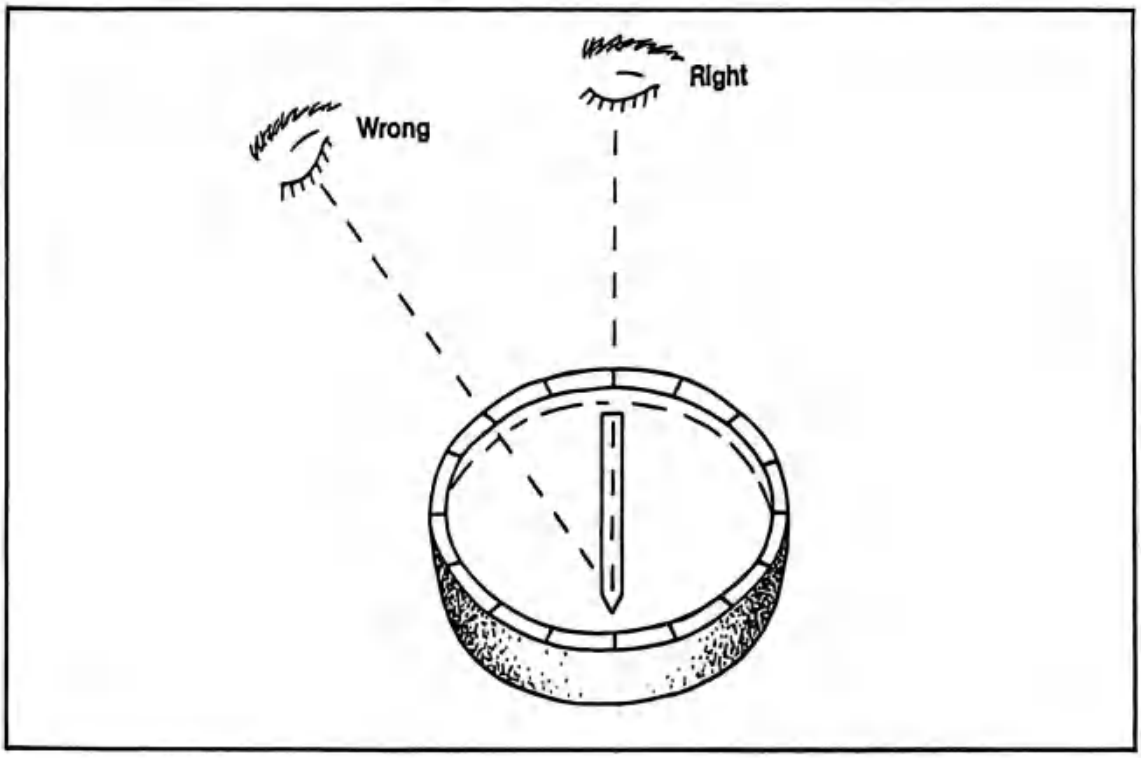



**Fig. 8-10 Avoiding Parallax Errors**

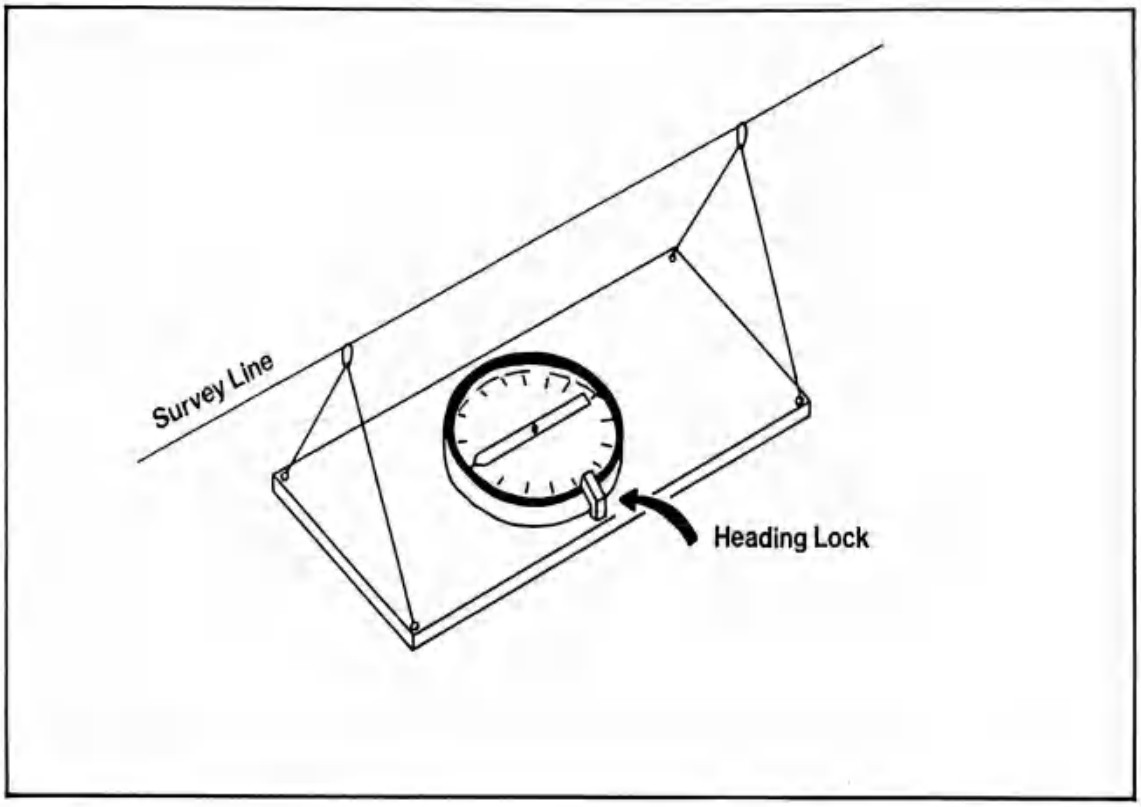



Fig. 8-11 Line Compass with Card Lock

optimum visual position for more accurate reading. The drawback, of course, is simply one more piece of gear and one more dangly. The compass also will have to be employed on near horizontal lines. However, there will be applications and situations where the line compass will be the preferred tool.

**SUMMARY**

In summary, there are special tools and ways of performing certain tasks in the survey process that allow you to gather data. Some of these tools and techniques are applicable only under certain conditions. Unique conditions require unique tools and methods. Creation of special tools and the development of techniques allow you to optimize the process. With proper attention to the tools you need and with adequate consideration to the ways in which you employ these tools, you gain the ability to gather accurate, reliable data in large amounts with more speed and efficiency than otherwise could be possible.

As mentioned previously, the techniques described here are ours. We use them, work well with them, and are generally satisfied with them. But there is room for improvement. We are continually refining. Using these methods as a starting point, you will save time and avoid mistakes. You will also develop your own refinements tailored to your survey projects. The development of refinements is a continuing process.

# SECTION 9

## SAFETY FIRST

INTRODUCTION

In the Forward section of the book I stated:

He who dives in caves a way
Can tangle with the worst
He'll live to dive another day
If he puts safety first

A rather simple little ditty but basic and to the point. Another one goes like this:

There was a young diver named Dave
Who found interests in a cave
His attention did stray
And he lost his way
The former young Dave was brave

We frequently make light of the risks inherent in the sport of cave diving, but some take it more seriously. The cover leaf of the book The Darkness Beckons by Martyn Farr of Britain states in part, "Cave diving is one of the most dangerous sporting pursuits known to man." However, the well trained and well informed cave diver knows that the risks can be reduced to a very comfortable and acceptable level with the use of proper equipment, with proper training and with the proper application of techniques and proven procedures. The well informed cave diver also recognizes that violations of the procedures and bending of the rules can and likely will induce problems leading to grave consequences.

We are assuming here that no one would undertake underwater cave surveying, or even consider it, unless he were a well trained, experienced cave diver. Anyone who reads this book should, if nothing else, pay notice to the following:

**IF YOU HAVE NOT RECEIVED TRAINING IN CAVE DIVING, DO NOT EVEN ATTEMPT TO ENTER AN UNDERWATER CAVE MUCH LESS ATTEMPT TO SURVEY ONE.**

The art of cave diving has its own facets of safety considerations both from an equipment viewpoint as well as from a procedural viewpoint. This work is not intended to be a tutorial on cave diving safety. Rather, it is meant only to highlight those aspects of underwater cave surveying that may tempt you to

bend a rule or to violate a procedure. Surveying is mostly procedural, and a number of pages in the preceding section have been devoted to techniques and procedures. You may have noted also that some of the most basic aspects of cave diving safety have been taken into consideration in the development of these procedures. In fact, the guidelines for technique development have been: safety first, simplicity in execution second, and efficiency third.

From strictly a safety viewpoint there are four aspects of surveying that may increase the risks inherent in the overhead environment. Given that you recognize these aspects going in, you can give them due consideration and turn them to your benefit to enhance your safety or certainly to preclude them from posing any additional risks. These aspects are:

1. The dangle dilemma
2. Preoccupation and task loading
3. The need for proximity planning
4. The drive for more data - the push factor

Let's take them one by one and give just a little consideration to each.

**THE DANGLE DILEMMA**

Any cave diver should be familiar with the term "dangle" and recognize immediately the dangle dilemma. A dangly is merely something (anything) that has the propensity to hang away from your body thereby increasing your profile and the chances of your getting caught in <u>something</u> - in the line, in the rock, in a hole, in your buddy's mask strap. Just the basic scuba equipment, lights, and lines needed to dive in a cave certainly present adequate opportunity for the dangle demon to strike. When you survey, particularly if you do a higher grade survey, you add to the list of potential dangles with extra reels, tapes, survey slates, helmets, markers, fasteners, hammers, and the like. I think there is some law just as fundamental as Boyle's law or Charles' law or Dalton's law or especially Murphy's law that goes something like...."The probability of entanglement is proportional to the square of the number of dangles." I call it the law of the Dangle Demon.

In surveying you are especially vulnerable to the Demon because you need the extra gear - the tools. You can, however, foil the Dangle Demon by using a little care and common sense and by giving a little thought to cleaning up your profile by tucking in and stowing. For example, I had special pockets made for both sides of my wet suit placed well below the hips - about half way to the knee. Perfect for stowing markers on one side, fasteners on the other. I also put a pocket on each sleeve, and I use an inner tube rubber band and retainers made from shock cord to stow unique items on my tanks such as long dowels. My tape has a

swivel snap and can be attached to a D ring and tucked under my harness sternum strap. I usually use a shorty wet suit with legs to a couple of inches above the knees over a Farmer John and hooded vest. The legs of the shorty are perfect stowage for small slates and extra decompression tables. My hammer, for magnetic deviation reasons as well, is tucked tightly into my harness waist band. There is no magic here, just a little forethought as to the sequence you will use the tools and where they are best stowed. The point is this - if it can dangle, stow it - and beat the Dangle Demon at his own game. And one last point. Incorporate a dangle check into your buddy predive safety check or S drill.

**PREOCCUPATION & TASK LOADING**

Second is the aspect of preoccupation and task loading. This is a tough one for me. Especially when I am busy studying the intricacies of some cave feature and sketching. I literally can lose track of time and become totally insensitive to the whereabouts of my buddy. "Self discipline," you might say. "Not so," says I. This is one of the primary purposes of writing each and every task to be done on the slate. Remember that admonishment in the section on Techniques and Methodology - the last paragraph under DIVE PLANNING? I stated, "write each task, numbered, on the slate." As in all of these techniques, there is a reason to do it that way.

Typical tasks as they would appear on our slates are shown here:

| Tasks JWB | Tasks FWH |
|---|---|
| 1. Radial 01-03 | 1. Radial 01-03 |
| 2. Radial 04-07 | 2. Radial 04-07 |
| 3. Location large dome | 3. Location small dome |
| 4. Sketch entrance Vp1 | 4. Sketch boulder Vp1 |
| 5. Circumsketch 01-02 | 5. Circumsketch 02-03 |
| 6. " 04-05 | 6. " 05-06 |

After completing each task the procedure is to check your buddy, air and time before proceeding to the next task. This checklist approach serves not only to insure efficient task accomplishment but to avoid the preoccupation syndrome which can cause you to neglect the basic checks. Preoccupation is real and can seriously detract your attention from the housekeeping chores of diving. This procedure is one answer to it. You may find a better one.

**PROXIMITY PLANNING**

Third is the need for proximity planning. Because of the quest for efficiency in the survey process, we frequently divide

the work load such that each member of the team may be doing a separate task not related to the other. Think the order of events through and plan the sequence in a manner that forces proximity of the divers. This thought was developed somewhat in two prior sections, and I will not reiterate here. You may be comfortable going off in one direction doing your thing while your buddy goes in the other direction doing his thing, and the two of you meet an hour later at the decompression stop. Not me! I want to know where my buddy is, and I want him to know where I am - all the time - and within a comfortable distance.

If you haven't given this much thought, and if you are inexperienced in underwater surveying, you will find yourself doing some rather stupid things at first. I would imagine that this phenomenon might even be worse for an experienced dry cave surveyor who is beginning in underwater surveying because he will have to unlearn some habits that are logical in a dry cave and anything but logical under water.

The first time this realization came upon me occurred when Frank and I were doing a high grade survey in a long passage and were using a tape. I was holding one end at a station as Frank took off with the reel down the passage unknowingly silting up as he put more and more distance between the two of us. As his light glow began to dim and all I saw was backscatter from the silt, I said to myself, "Self, this is dumb. Frank is tooling on down a clear passage putting big time distance and silt between us while I am here parked in the silt on the ceiling wondering what he or I would do exactly if either of us had a serious air problem. JB, ole boy, I think the prudent thing to do is to close the gap." With that thought in mind I tied off the tape end and followed it to Frank. He was surprised to see me; but as soon as he did, he realized what we had done. We took the measurement and swam back to the tied off tape end - together. It was then and there that the concept of proximity planning came into being - at least for us.

I could pontificate and wax long and arduously on innumerable ways a team can proximity plan. As a practical matter, however, each dive is different and each dive must be planned accordingly. With the concept of proximity planning in mind, logic will prevail as you sequence your dive task assignments. A few "dry run" walk-throughs will also help you to identify problem areas here and to modify your task sequence planning accordingly.

## THE PUSH FACTOR

Fourth is the drive for more data - one last leg - a little more detail. Just that one odd feature. What lies just around the next turn in the passageway? You are at air turnaround, but your buddy is still busy on his tasks and not quite through yet. After all, you aren't planning to survey outbound, and you're

exiting with the flow. He's just about done now ... just a few more minutes. You don't want to have to do another dive just to get these last two cross sections. The push factor!

If you're a cave diver, you don't have to be a surveyor, you've been there. The push factor is worse in surveying. I recently turned a dive when we had only one more station and less than 50 feet to go. But I was tempted! Had I not had a little problem with my stage tank regulator stashed some 500 feet in from the entrance with some 700 feet between me and that stage tank, I might have pushed for that last station and 50 feet more. If I had, it would have been stupid .... bending the rules. Air turnaround means air turnaround. Other than a bona fide problem, there is no acceptable reason to violate this rule!

Here you might say again, "Self discipline." And I say, "You're absolutely right!" We haven't found a check list or a procedure yet that will force this factor out of the equation. The only guard against the push factor is an absolute agreement that no member of the team will push, that thumbs go up at air turnaround, and we all know that thumbs up means thumbs up - no questions asked and no apologies! It's tempting, I agree, but as the ditty writer said:

There was a macho diver named Fred
Who was somewhat hard in the head
He pushed on his air
Till his tank was quite bare
Now macho Fred is dead

Other than these four factors which are somewhat peculiar to and pressing on the surveyor, we know of no others that add risk. And these can be coped with and incorporated into procedures, for the most part, which will focus you on a more disciplined and safety oriented dive profile. The desire to get the job done can cause one to overlook higher priority considerations of safety. But if planning is done properly and procedures are developed and thought through thoroughly, then safety consideration will find its way into the priority scheme where it belongs .... SAFETY FIRST!!

# SECTION 10

## CRUNCHING DATA

### INTRODUCTION

In accounting and in technical circles, crunching data is jargon which alludes to the manipulation and or processing of large amounts of information or data usually expressed in terms of numbers and symbology. We have plenty of both in the underwater cave survey process.

Considerable verbiage has been devoted so far to the techniques and procedures developed to enhance your ability to measure and to gather data and to record it as well. Here you will examine the formats used in recording all this data and what is done with it.

### SURVEY SLATE FORMATS

Consider the recording of data on the exit of an initial penetration where the objective of the dive might be penetration and exploration with survey on exit.

Of course you would have laid the line inbound in a point-to-point manner all tight and ready, and you would have with you a survey slate laid out in a format as shown in Figure 10-1.

As you can see from this format, it is organized to enable you to record data in the sequence you gather it with appropriate abbreviations: STA (station), DPTH (depth), AZ (azimuth), DIST (distance), REF (reference) and REM (remarks). As you begin the survey at station 00, you measure the depth at the station marker and insert the information on line 00 under column DPTH. Next you take an azimuth reading and record that information on line 00 under column AZ. If you wanted to gather additional data with reference to the line such as left wall, right wall, ceiling or floor, you would record that on line 00 under column REF. Additional data or remarks would be recorded in "cave shorthand" on line 00, column REM. Having gathered and recorded all the data at station 00, you then move down the line, counting knots as you go to the next station, 01. At 01 you record the number of knot intervals you counted, i.e. 5.7, on line 00 under column DIST. If you were time limited and doing literally a stick map survey, you would record only DPTH, AZ and DIST and maybe some very abbreviated remarks. More detail could be sketched or recorded under column REM.

CAVE: _____ TEAM: _____ DATE: _____

| STA | DPTH | AZ | DIST | REF | REM |
|---|---|---|---|---|---|
| 00 | | | | | |
| 01 | | | | | |
| 02 | | | | | |
| 03 | | | | | |

Fig. 10-1 Slate Format - Passage

If you were surveying a large room, you would lay out the survey slate in DAD format but probably omit the REF column and change the REM column to RAD (radial) as shown in Figure 10-2.

Here again you can see that the format of the data to be recorded is in the sequence in which it is to be gathered.

CAVE: _____ TEAM: _____ DATE: _____

| STA | DPTH | AZ | DIST | RAD | AZ | DIST |
|---|---|---|---|---|---|---|
| 00 | 22 | 005 | 27/5 | 03 | 047 | 33/6 |
| 01 | 23 | | | 03 | 093 | 27/0 |
| 02 | | | | | | |
| 03 | 29 | | | | | |

**Fig. 10-2 Slate Format - Room**

This format, or some variation of it, is the standard format for recording underwater cave survey data. You will find that you will adopt a variation to best enable you to record the data you are emphasizing. For example, you may want to do a sketch of the side wall between stations.

You will recall that in the section on Techniques and Methodology, the procedure for surveying a large room was described. First, the line was laid from station 00 around a closed loop back to 00. Next, DAD was taken for all legs again around the loop to 00. Then radials were taken and recorded on the same slate. Once DAD on each leg of the circumline is recorded in this format, you need only to record the radial station number in the RAD column, the radial azimuth in the AZ column and the radial distance in the DIST column. The depth of each station has been recorded previously. In this illustration you can see that the radial from station 00 to station 03 has an azimuth bearing of 047 degrees with a distance of 33.6 feet. (We prefer to use a slash versus a period for a decimal point due to the difficulty in writing on a slate under water. The slash takes a more deliberate stroke of the pencil.) Likewise the radial from station 01 to station 03 has an azimuth bearing of 093 degrees with a distance of 27.0 feet. Since a depth of 29 feet for station 03 was recorded previously on the first time around the legs taking DAD, there is no need to duplicate that measurement. If you intend to take more than one radial from any station, merely leave adequate room to record several lines of data under the RAD columns.

**SKETCHING FORMATS**

Formats for sketching are a little different. Before you begin sketching, you should have completed the line plots and closed the loops as necessary for the accuracy you require. Then draw the line plots - to scale- on your sketch slate to serve as the reference base for all other measurements and estimates. Therefore, the formats of the slates take the form of the line plots. On long passages a fast and efficient technique is to have one diver do one side wall and another diver do the other, although a single diver can do both. The format for this approach is shown in Figure 10-3.

Here you draw in the survey line - to scale - in the vertical plane and insert a scale block for referencing distances to the line during sketching. In this example, station 00 is on the right wall, 01 on the left, 02 on the right, 03 on the left and so on. The passage is 10 feet wide. One diver's sketch will appear on the slate as the solid line. The other diver's slate will appear as the broken line. And so on. You can see that as two divers swim the line from 00 toward the higher numbered stations, each concentrating on one sidewall as referenced to the line, a very accurate representation of the sidewall can be obtained. With a little practice this technique

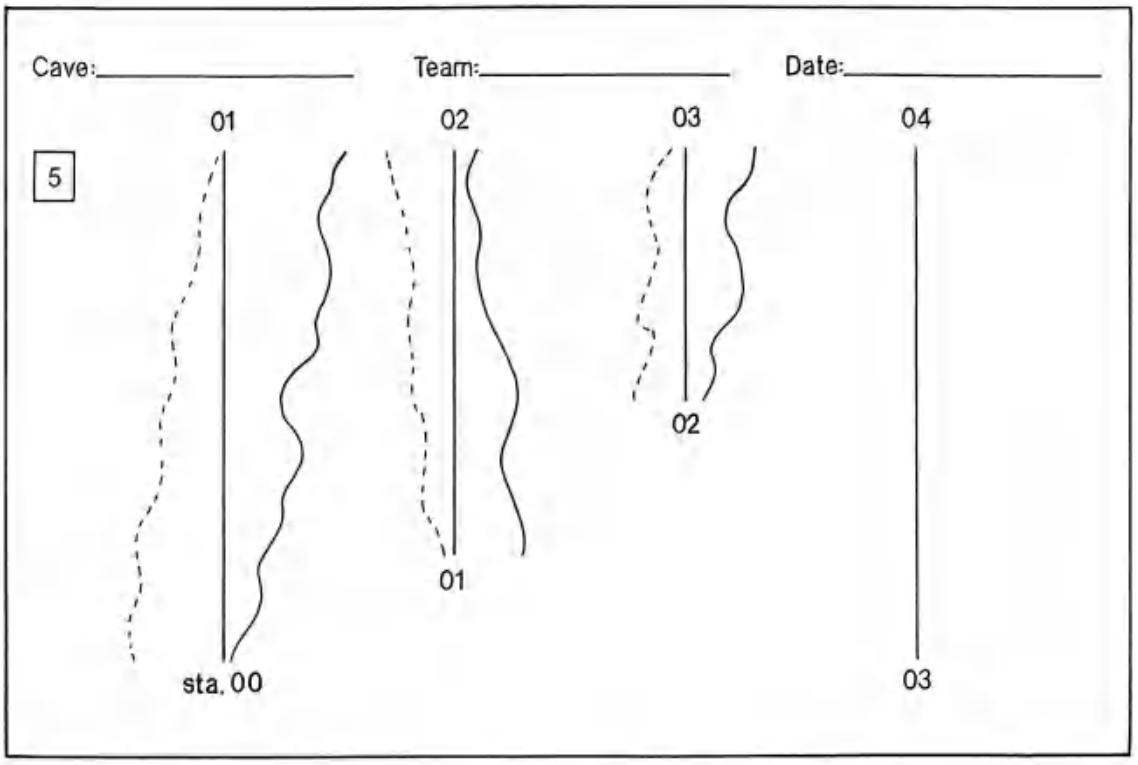



Fig. 10-3 Slate Format - Sidewall Sketch

assures that every foot of sidewall is visually observed as it is sketched. Nothing is left to memory, and verification is simple so long as permanent station markers are left in the cave.

**SURVEY SHORTHAND**

Obviously, you can recognize the need for a diver to be able to record data and to make notations on slates under water in the most descriptive terms possible. These data and notations must be developed later into calculations, drawings, notes and descriptive phrases to be expressed both in words and in unique symbology. Thus the need for "survey shorthand."

There are some standard forms of notations that are generally accepted and widely used by underwater surveyors. These are shown in Figure 10-4. There is no formal standard, however, and each diver will tend to develop his own - probably meaningful only to himself. This is an area which needs to be developed more by the cave diving survey community. I know some surveyors who are quite proficient in gathering massive amounts of information on the smallest of slates. But you try to make sense out of it! If anyone else ever has a need to use their data - too bad. You should use standard map symbology as much as possible to make interpretation easier. This subject is treated in more detail in the section on Symbology.

Survey shorthand is not well standardized and is not likely

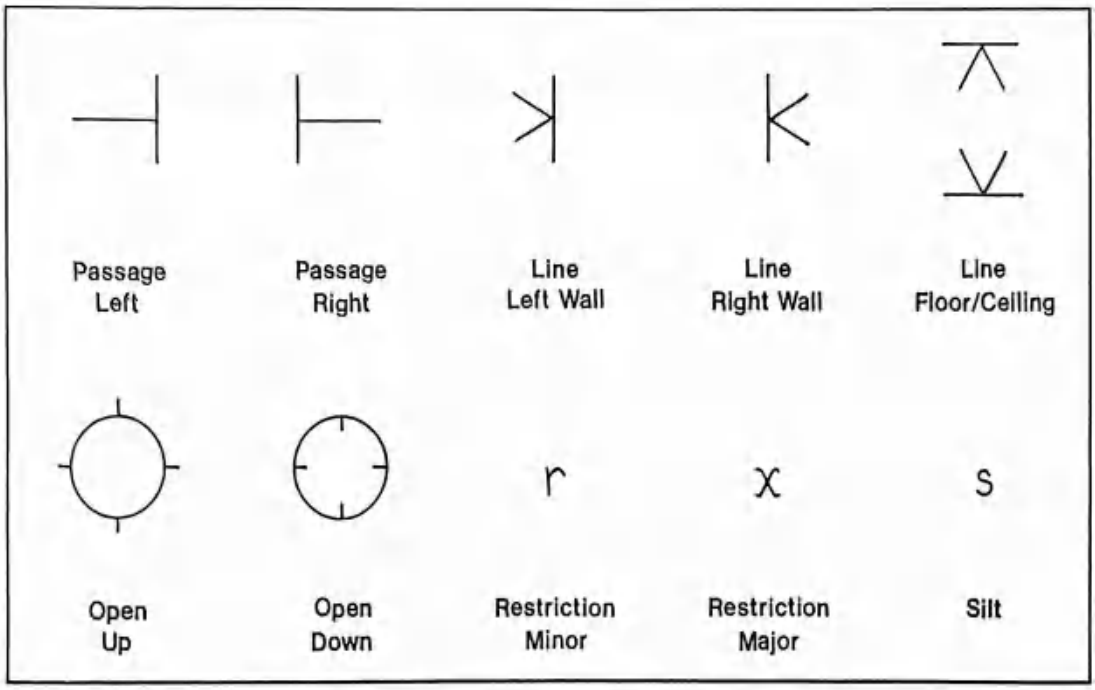



Fig. 10-4 Survey Shorthand

to be in the near future. Therefore, the shorthand in use is very much unique to the individual diver so it is imperative that the divers translate their shorthand as they transfer the data from slate to permanent record.

## DATA TRANSFER

After you have recorded the data under water and brought it to the surface, what do you do with it? If you plan a repetitive dive, you need to process some of it at the site for use on the next dive. In any event you need to clean up the data, translate and expand on the "shorthand" and transfer the information from slates to a permanent record.

The data is transferred to permanent form for future use in drafting and verification. It is strongly recommended that any and all notes be developed to the point where interpretation is absolutely clear, and the notes are vividly descriptive and meaningful to anyone who may have need to interpret the data. For example, slate shorthand may indicate a passage to the left at station 09 with "+10 s --- 4/5 ^^ >." The notes as transferred to the permanent record for station 09 would read, "passage to left 10 ft past station 09, silty, clay bottom, 4 ft high, 5 ft wide, slopes down, flow out, X section see sketch."

When the map is being drafted - perhaps days, weeks, or even months later - such descriptive notations will be invaluable

in enabling the cartographer to develop an accurate representation of what the surveyor had observed - particularly if the cartographer was not the surveyor! Many a survey has lost much of its potential for detail and accurate representation simply because the data got stale.

## DATA MANIPULATION

Here you will need to devote a little time to high school mathematics. You will recall that Depth, Azimuth, and Distance to the next station were recorded at every survey station. Let's look at that a moment in Figure 10-5.

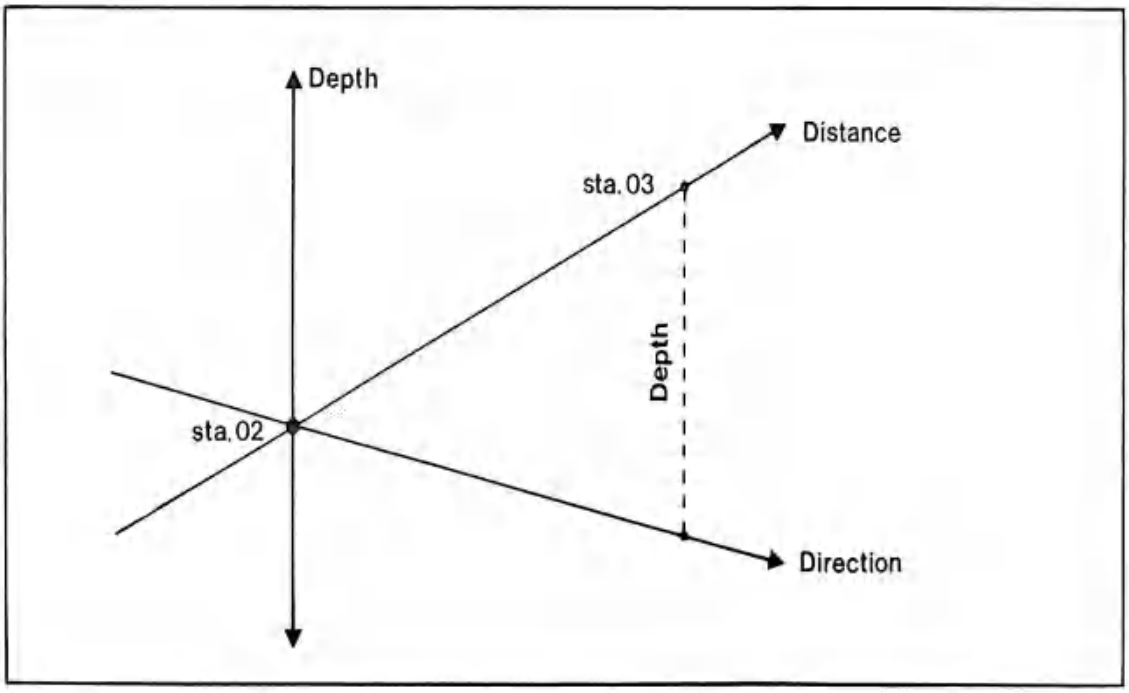



Fig. 10-5 Relative Station Positions

What is actually being recorded at station 03 is a set of polar coordinates relative to station 02 expressed in terms of direction, distance and depth. You have data expressed in three dimensions and two planes. The problem for the cartographer is that maps are not 3-D and can be made in only one plane. Therefore, you must manipulate the data such that the same information can be expressed in only one plane. Stated another way, by compensating for the distance variation introduced by depth differences, you can eliminate a plane.

Looking at it in one plane only, consider the viewer of the map looking straight down from above, called a plan view, as illustrated in Figure 10-6. Here you can see the problem more clearly. The actual line measurement from station 02 to station 03 is 30 feet; however, as you view that measurement from directly above, the apparent distance from station 02 to 03' is

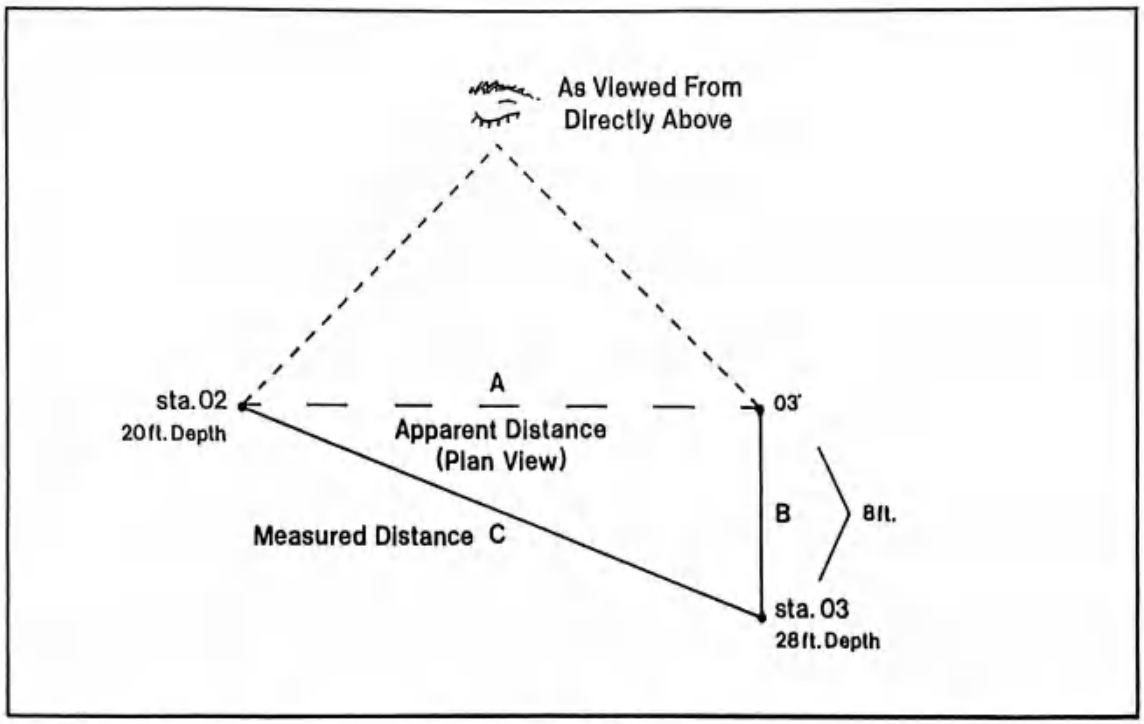



Fig. 10-6 Plan View

shorter than 30 feet. Therefore, in order to represent the leg 02-03 on a map to the viewer, you must correct the measured distance of 30 feet to the apparent distance. In other words, you must convert the measured distance (side C of the triangle) to the apparent distance (side A of the triangle). This is referred to as the plan view distance and will be the distance used on the map by the cartographer.

Here is where the high school arithmetic comes into play. What data do you have? You have depth of 20 feet at station 02. You have the measured distance of 30 feet from station 02 to station 03, and you have depth of 28 feet at station 03 or a depth difference between the two stations of 8 feet. Now all you have to do is to apply the pythagorean theorem to the right triangle. Remember that?

$$A^2 + B^2 = C^2$$

A is the base of the right triangle (02-03).

B is the opposite side of the angle (03-03') or 8 feet.

C is the hypotenuse (02-03) or 30 feet.

Applying the theorem $A^2 + B^2 = C^2$ we see that:

$A^2$ (to be found) + $B^2$ (8 X 8) = $C^2$ (30 X 30) or

$A^2 + 8^2 = 30^2$, or $A^2 + 64 = 900$, or $A^2 = 900 - 64$ or

$A^2 = 836$, or $A = \sqrt{836}$, or $A = 28.9$ ft.

Whenever there is any meaningful difference in depth from survey station to survey station, this data crunching (manipulation) step must be taken. We call this process "plan view distance correction."

There is a simpler method to execute this process, however. The graph shown in Figure 10-7 can be used in most cases to solve the pythagorean theorem rather than having to go through the arithmetic. Simply select the line distance measured between survey stations along the base line of the graph, follow the curve up to where it intersects the depth difference between the two stations, and read back down to the base line for the corrected distance.

Looking at Fig. 10-7, a line measurement of 55 feet with a depth of 25 feet at one station and a depth of 50 feet at the other station would be corrected to 49 feet. From 55, follow the curved line up to 25 (50 - 25) and then back down to 49.

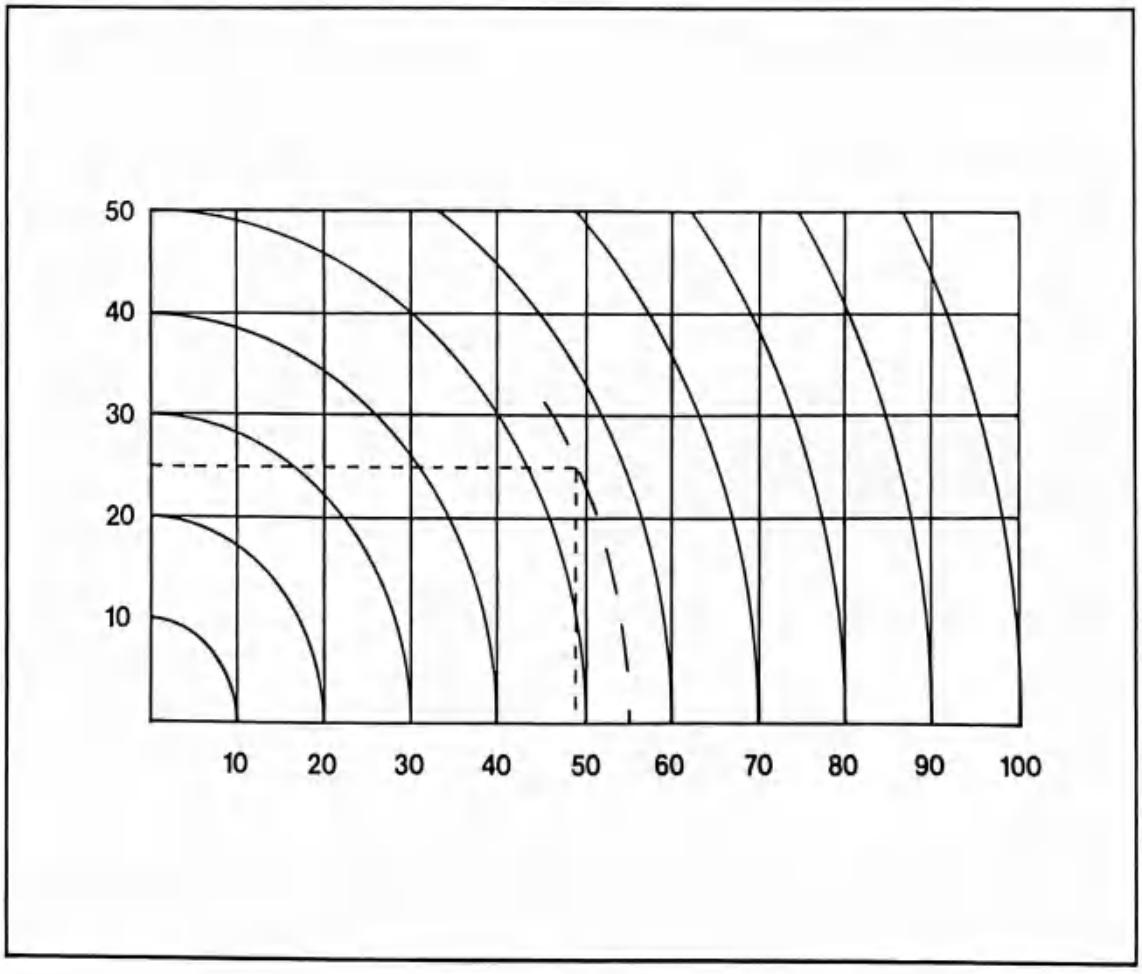



**Fig. 10-7 Plan View Distance Correction**

Use of this simple graph will preclude your having to do the mathematics of extracting the square roots, which can be a little time consuming if you are doing this exercise at the dive site without a calculator.

## FINAL NOTES AND PERMANENT RECORD

The slate notations have been translated and expanded. The plan view distance corrections have been calculated. All that remains to have a clean data base is the organization and recording of all this information into a permanent record. It is this permanent record that will be used by the cartographer in the construction of every detail of the final cave map.

A word or two on the permanent record here. I mentioned earlier that we use a standard 3-ring hard-back note book with separators and standard 1/4 inch quadrille paper. We do not preformat the pages, but we do record all the data exactly as we put it on the slates except for the notations and remarks which we do interpret and expand upon. We always pay particular attention to the recording of the data into the permanent record and use a great deal of care and double checking to avoid translation and transfer errors.

A typical permanent record page is shown in Figure 10-8. Note that each page is annotated with the cave name, the team, the date, and the page number of the pages - for each dive. For example, if two dives had been made on the same date and two pages of data had been recorded on the first dive and three pages on the second dive, the data record for the first dive would be pg 1 of 2/ dive 1 and pg 2 of 2/ dive 1. The data record for the second dive would be pg 1 of 3/ dive 2 and so on. Note also that the plan view distance corrections have been made for all legs. In other words, you should make an accurate, permanent record which, incidentally, should contain not only your survey data, but any and all other data relating to the project: photographs, draft maps, memory ticklers, log references, correspondence, copyright applications and so on.

We also duplicate this record for each member of the team so that we can all work from and refer to the same data base when we are not together and have to communicate via correspondence or telephone.

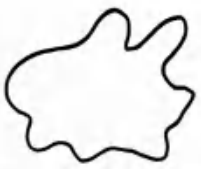
Many times you will probably be doing line plots at the site in order to transfer that to a slate for further sketching and recording of features and other details on a repetitive dive. These line plots also should be entered into the permanent record book as part of your working data.

The line plot for the data recorded in Fig. 10-8 is shown in Fig. 10-9 as it typically would be done on site with just a protractor and a rule.

Cave: Spooky Team: JWB/FWH Date: 12/6/86 Page: 1 of 3/D1

| STA | DPTH | AZ | DIST | FL | CL | RAD | AZ | DIST |
|---|---|---|---|---|---|---|---|---|
| 00 | 33 | 033 | 25.5 / 25.3 | 35 | 20 | 03 | 069 | 91.5 / 91.5 |
| | | | | | | 04 | 081 | 86.0 / 86.0 |
| 01 | 30 | 065 | 35.0 / 34.9 | 34 | 22 | 04 | 094 | 85.9 / 85.8 |
| | | | | | | | | |
| 02 | 32 | 095 | 40.2 / 39.9 | 36 | 27 | 04 | 111 | 58.0 / 57.9 |
| | | | | | | 05 | 170 | 55.0 / 54.7 |
| 03 | 34 | 140 | 23.4 / 23.4 | 38 | 25 | 05 | 211 | 58.0 / 57.4 |
| | | | | | | | | |
| 04 | 35 | 235 | 55.1 / 54.4 | 40 | 20 | | | |
| | | | | | | | | |
| 05 | 26 | 262 | 58.4 / 58.0 | 31 | 20 | | | |
| | | | | | | | | |
| 06/00 | 33 | | / | | | | | |

Exit Vpl



Note: 1) Dome directly over STA 03

2) Vpl 15' from 00 on 00-03 RAD

2

Fig. 10-8 Permanent Data Record

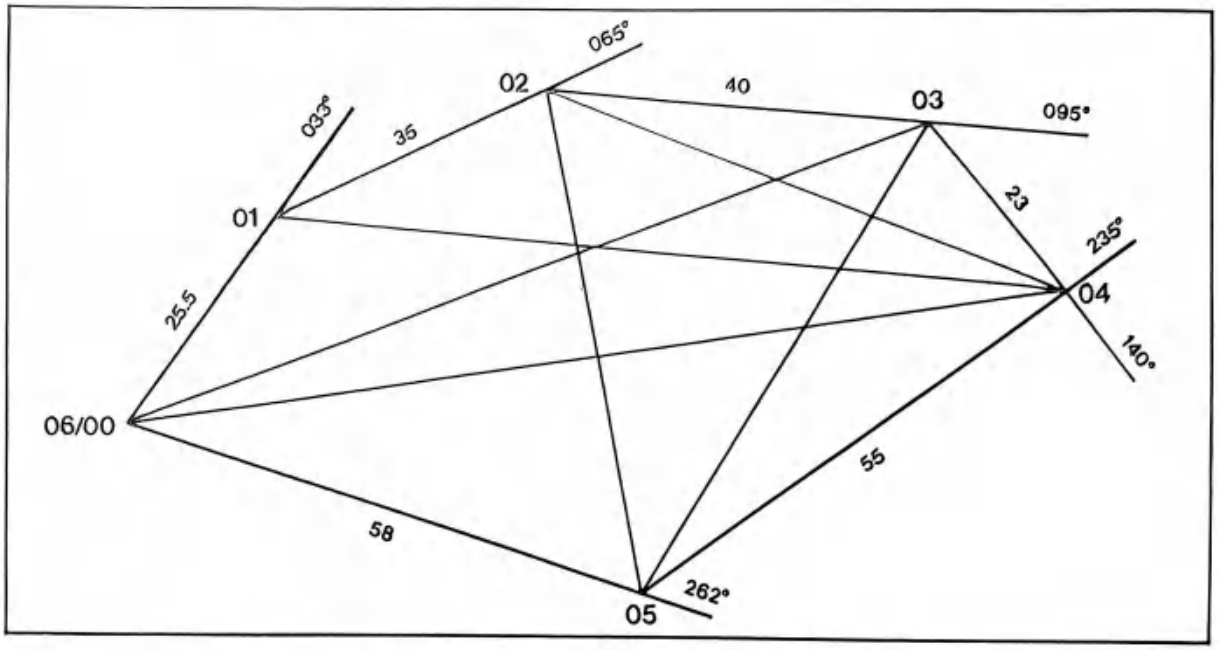



Fig. 10-9 Working Line Plot

**SUMMARY**

In summary, the data crunching process involves all the steps:

- The initial recording of information on a slate
- The development and expansion of that information
- The mathematical corrections of the distances due to depth variations
- The final recording and duplication of a permanent record

I cannot over emphasize the importance of attention to detail when taking data from the slate and transferring it to the note book. Nor can I over emphasize the importance of having clear, descriptive notes when it comes to transforming data from the note book to a good, working draft map.

Having developed a good set of permanently recorded survey data, you are ready to proceed to the next phase and examine the symbology you will be using to translate all your data into "cavemapese" in the cartographic phase.

# SECTION 11

## SYMBOLOGY

### GENERAL

Symbology is the hieroglyphics of cartography - a form of shorthand, so to speak. However, this shorthand, unlike the non standardized cave survey shorthand, is much closer to standardization. Thank Goodness! Otherwise no one would be able to read any maps! Map symbology is simply a means to convey a lot of information with a little bit of data.

As long as people have been making maps, symbology of some kind has been used to express visions of certain images, and we underwater cave surveyors are no exceptions. One would think you could turn to a single source - a book or a guide - and have a ready reference to "standard" map symbols - a dictionary of a sort. One to which everybody refers. Well, you can and you can't. You can find lots of publications with cave map symbols. Most of them are very, very much alike. That's one of the problems, however. They are very, very much alike - not exactly alike.

### SOURCES

I have researched a number of sources hoping to find a "standard" set of symbols. There are conflicting symbols in the data such as one source offering a certain symbol with a specific meaning and another source offering a dissimilar or different symbol for that identical meaning. For the most part, however, I have found only a few such conflicts for symbols applicable to underwater cave maps.

Within the United States, there are numerous listings of "standard" symbols. The most widely circulated of these, so far as I have been able to determine, are those published by:

- The National Speleological Society
- The Missouri Speleological Survey
- The Association for Mexican Cave Studies
- The American Geological Institute
- The U.S. Geological Survey
- The British Cave Research Association

The only listing I have found which is oriented specifically to underwater caves is a very abbreviated list of symbols contained in Chapter 14 of the National Speleological Society NSS

Cave Diving Manual, although I am sure that there are others. The point is, however, that there is not a nationally or internationally recognized and accepted single set of "standard" map symbols for underwater cave maps. There may never be. On the other hand, there are symbols commonly used and suggested by virtually all the various agencies that have published sets of symbols which we have consolidated here as the optimum set of symbols - in my opinion - for underwater cave maps. They are all widely recognized and should not be controversial. Where conflicts existed, we have selected the most widely accepted symbol according to our research.

Another point concerning symbology. If you are going to invest the time and the effort and expend the resources to do a survey of an underwater cave and then devote the effort to the cartography to create a map, **by all means .... include a legend**! Now, you don't think for a moment that most of the people who may read your map have a complete vocabulary of cave map symbology tucked away somewhere in the corner of their gray matter, do you? Why certainly not! Even those of us who spend reasonable amounts of time on the subject can't be expected to have much more than a fair working knowledge, much less be fluent in underwater "cavemapese."

## RECOMMENDED SYMBOLOGY

Following in this section is a compilation of those map symbols published by one or more of the agencies cited previously and which, in our judgement, you may find a reasonably frequent need to use in an underwater cave map. I don't represent this compilation as the authority, nor do I attest to its absolute completeness. I do feel, though, that you will find an appropriate symbol in this compilation for the vast majority of features and or notations you may wish to express cartographically with the use of a symbol. I also propose this compilation to the U.S. agencies that certify cave divers as the baseline from which to build in the future as required for underwater cave map symbols (NSSCDS, NACD, YMCA, NAUI) as well as to the other agencies that offer cavern specialty courses.

Perhaps some day in the future this compilation or a similar one will be adopted formally as "standard" by all the U.S. agencies that have any input - training, publication, reproduction - into the process of generating underwater cave maps.

## SYMBOLIC REPRESENTATION

One final point. A really good, effective and communicative cave map is one in which the reader can see the picture or the image that the surveyor saw and that the cartographer is trying to convey. After all, that is the primary

purpose of the map in the first place. It stands to reason then that the symbols as much as possible, within reason, should look like what they represent. Therefore, when applying these symbols, the cartographer should use care and put forth special effort to apply the shapes and relative sizes accordingly and where appropriate.

## SYMBOLS

Figure 11-1 is the compilation of the symbols we have culled from our source documentation as the optimum representation of those symbols most widely recognized as applicable to the underwater cave.

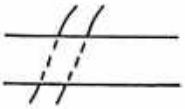
Fig. 11-1

CONVENTIONAL UNDERWATER CAVE MAP SYMBOLS

Surveyed passage walls

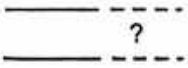
Explored but unsurveyed passage walls

Observed boundary

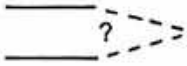


Underlying passage

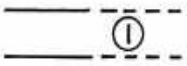
Overlying passage




Unexplored passage




Unexplored passage - Too narrow

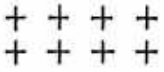


Unexplored passage - Too low

Walls obscured by secondary mineralization

Stalactite

Stalagmite



Crystallizations

Column - black ceiling - white floor

Water depth at floor

Height floor to ceiling

Vertical floor difference - ledge

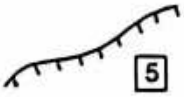
Slope - Splayed down hill

Dome - Ceiling

Pit - Floor

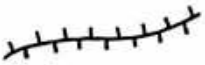
Pit - Depth below floor

Dome - Height above floor

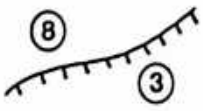



Floor - Ledge - Dimension on lower side

Dome/ Pit - Floor to ceiling height



Ceiling channel - Crack



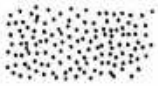

Ceiling ledge - Splayed to lower

Direction of Flow

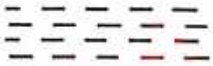
Intensity of Flow - relative

Boulder

Breakdown



Sand

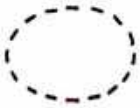


Clay or Mud

Rock fragments

Gravel

Limit of Daylight - Optimum conditions

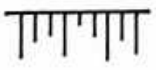


Outline of Surface Pool

Vertebrate Remains

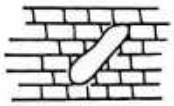
Invertebrate Remains

Vegetal Debris



Soda Straws

Archeological Material



Showing structural control

Survey Station on Line

Scientific Notation - Location of Sample

Camera Location - Photo view

Viewpoint

Section Line - Arrow view direction

Cross Section

Survey Station Marker

p1505

Penetration - Distance to nearest exit qualified by notation

Z

Zero visibility can be expected

S

Silty or silt can be expected

X

Restriction - major - Diver with doubles cannot pass

r

Restriction - minor - Tight but 2 divers can pass

# SECTION 12

## CARTOGRAPHY

### INTRODUCTION

As stated in the section on The Survey Process, Webster defines cartography as "the science or art of making maps," and I further added that for purposes here it is the transformation of data, notes, sketches and drafts into a reproducible document in the representation of a cave. Here is where it all comes together. All the planning, data records, the sketches, and interpretations are transformed into a visual image. If the quality of the survey has been high, then the investment of time and effort has been significant; and you should certainly do it justice.

You have a number of considerations to take into account in the drafting of the map. Some of these are technical considerations that have to do with the basic accuracy of what is drawn. On the other hand, there are numerous factors to consider which have to do not with the information per se that is on the map, but how that information is perceived. That is, what is emphasized versus what is deemphasized and what is aesthetically pleasing to the viewer. A well balanced, clean, graphically proper map will actually convey more information to the reader than will one which is graphically incorrect, even though the information may be identical on both. In other words, how good a job you do as a cartographer determines to a very large extent how much information you will be able to communicate to the reader. Never thought about it quite like that, did you? Let's take a look at some of these considerations.

### THE MEDIUM - DRAWING MATERIAL

One of the first decisions to be made is the selection of the medium to be used for the drawing. That is, what kind of paper should you use? Actually, you have several choices for the working drawing but only a few choices for the final map. The first drawing of every map should be a working drawing which can ultimately be used as the tracing template for the final product. Since the first drawing will be literally a working document, it should have the qualities which make it durable, which enable it to withstand erasure easily and which enable it to resist tearing. Depending on how much the drawing will be used in terms of making changes and handling, the choices range from plain bond to tracing paper to vellum. Generally, the preference is vellum or a high quality tracing paper with blue 10

units per inch quadrille. The blue overprint is a tremendous aid in drafting and will not reproduce. This paper is available in rolls, tablets or sheets and in various thicknesses. Because we actually reproduce copies of our working drawings for use by other members of our survey team, we obviously favor the translucent tracing paper or vellum which can be reproduced by xerox, diazo or photography as required.

## PLOTTING METHODS

Next you must lay out the line plots and close the loops if that process has not already been done. There are two methods of laying out line plots:

(1) Use a protractor and a rule and simply lay out on paper the azimuth direction and the plan view corrected distance of each leg from station to station. This is typically the method most commonly used in the field. However, if you have a scientific calculator, the next and more preferred method will be very easy.

(2) Convert each station location to cartesian coordinates (also known as polar or rectangular coordinates). For accuracy in plotting, this is the better method since the plotting errors are not cumulative, and each point is located on the map relative to its own set of coordinates rather than in relation to where the preceding point falls on the map. Additionally, the layout of the map on the paper is greatly simplified because you can tell exactly where all the points will lie by their coordinates without having to plot the entire line plot or framework. Although we frequently use method 1 in the field, we nearly <u>always</u> use method 2 when laying out the map for drawing.

The process of converting the survey data to cartesian coordinates was not covered in the section on crunching data since it is more a part of the cartographic phase than the data manipulation phase. This process will be explained in this section since it is the preferred method of laying out the data for the actual drawing of the working map or tracing template.

## CARTESIAN COORDINATE CONVERSION

Taking a set of station data as you would have recorded it in your permanent record book shown in Figure 12-1, we shall convert to X and Y coordinates and demonstrate a line plot.

Note that we have entered the correction for plan view distance which will be the figures we use. With station 00 as the starting point and by using the distance and direction to the next station, you can calculate both the X (east - west) component and the Y (north - south) component of the coordinates

| STA | DPTH | AZ | DIST Meas/Plan |
|---|---|---|---|
| 00 | 20 | 025 | 25 / 24.5 |
| 01 | 25 | 050 | 30 / 29.6 |
| 02 | 20 | 095 | 20 / 19.8 |
| 03 | 23 | 135 | 35 / 34.1 |
| 04 | 15 | | |

Fig. 12-1 Station Survey Data

with the application of some simple trigonometry functions:

Calculate the X (east/west) component:

Sine Azimuth Bearing = X ÷ Distance

X = (Distance) (Sine Azimuth Bearing)

For station 01, X = (24.5) (Sin 25)

X = 10.4

Next, calculate the Y (north - south) component:

Cosine Azimuth Bearing = Y ÷ Distance

Y = (Distance) (Cosine Azimuth Bearing)

For station 01, Y = (24.5) (Cos 25)

Y = 22.2

The coordinates for station 01 in (X,Y) format are: (10.4, 22.2).

To complete the process, continue the same calculations for

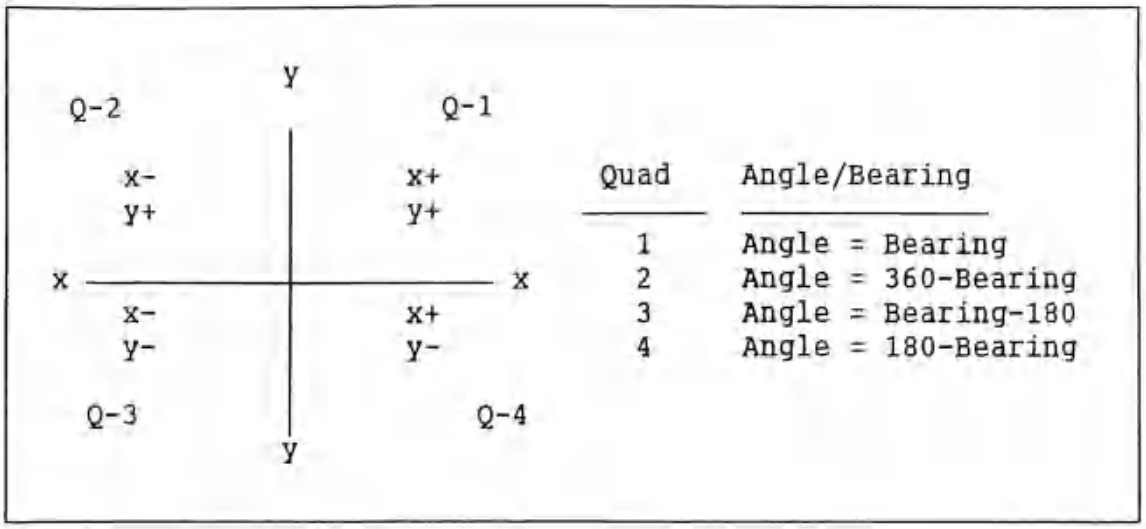



Fig. 12-2 Angle/Bearing Conversion By Quadrant

each station. Note that azimuth bearings are used in making these calculations. It is imperative that you pay particular attention to the correct algebraic sign used for the coordinates. It is also necessary that the compass bearings be converted to the proper angles, as well, to perform the trigonometric calculations. This conversion to the proper algebraic sign is necessary when using abbreviated tables of trigonometric functions. Figure 12-2 denotes both the proper algebraic sign to be used by quadrant and the conversion of compass bearing to angle. However, commercial electronic calculators which incorporate trigonometric functions build in this conversion and will automatically assign the proper algebraic sign as well as convert the bearing to angle.

When converting a number of stations to cartesian coordinates, you will find it easier to organize your data by constructing a table as shown in Figure 12-3.

Since you must plot each coordinate independently and in relation to (0,0), each coordinate must be added in a cumulative manner algebraically. From this table of cumulative coordinates you construct the line plots on the draft tracing paper.

**LINE PLOTS**

As you can see by studying the table of cumulative coordinates for the line plots, the framework of the map limits in relation to (0,0) is quite evident. It is but a simple observation then to place the map framework without having to actually construct the line plots as would be the case if you were to use the protractor and rule described in the alternate method. This cartesian coordinate method is more accurate because each point is determined independently and is not dependent upon where you actually placed the pencil for the

| STA | AZ | DIST | X | Y | CUM X | CUM Y |
|---|---|---|---|---|---|---|
| 01 | 025 | 24.5 | 10.4 | 22.2 | 10.4 | 22.2 |
| 02 | 050 | 29.6 | 22.7 | 19.0 | 33.1 | 41.2 |
| 03 | 095 | 19.8 | 19.7 | -1.7 | 52.8 | 39.5 |
| 04 | 135 | 34.1 | 24.1 | -24.1 | 76.9 | 15.4 |

Fig. 12-3 Table of Cumulative Coordinates

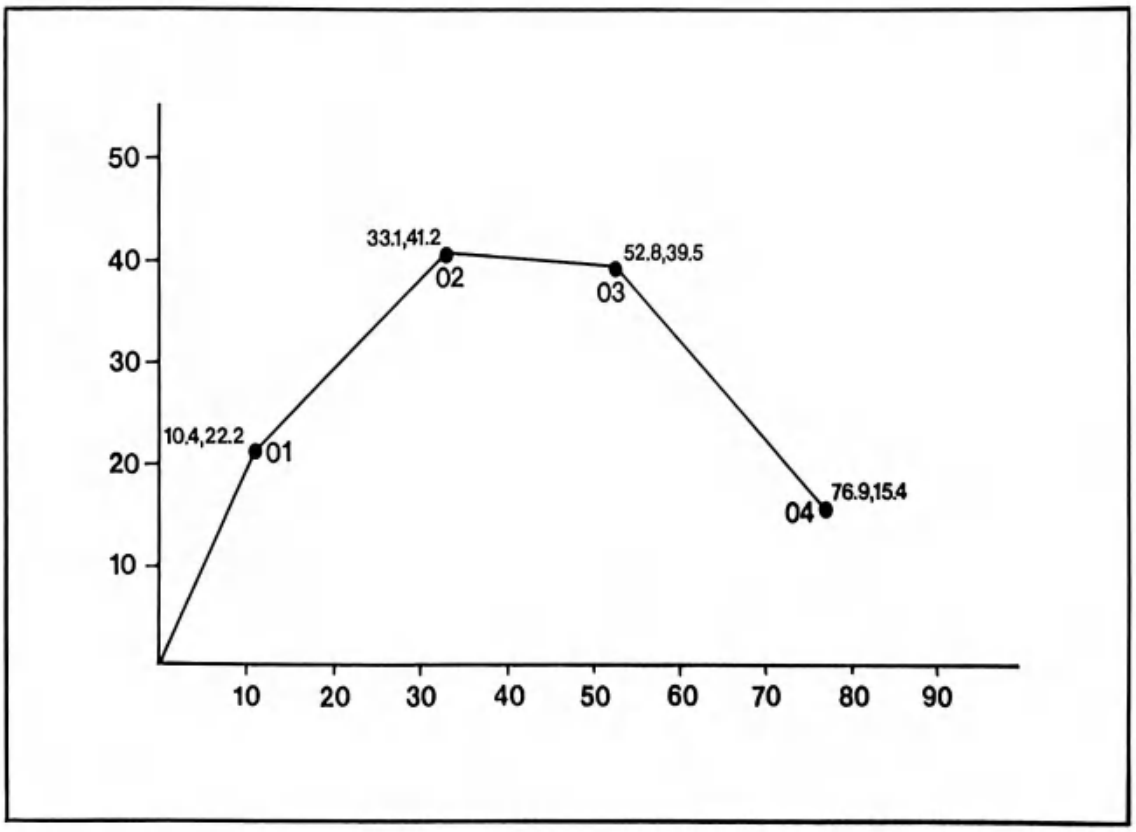



Fig. 12-4 Plot of Cartesian Coordinates

preceding point on the paper as it would be with the protractor/rule method. This method also lends itself perfectly to more sophisticated computer techniques. There are computer programs available that will take the raw DAD data and convert it

directly to a table of cumulative coordinates. Driving a plotter to construct line plots from a computer with this software is a simple matter. You need only to understand the process for this purpose, however. You may implement it any way you choose.

Using the same coordinates calculated and tabulated in Figure 12-3, a sample line plot has been constructed and is illustrated in Figure 12-4.

## LOOP CLOSURES - ERROR CORRECTIONS

Next you must deal with loop closures and error corrections if you have not already done so. In every survey there will be errors and, hopefully, you would have done sufficient verification to reduce these errors to acceptable limits to meet your accuracy objectives. Even then, the loops won't close completely on paper so you must make the appropriate corrections to the data for drafting purposes.

If you wish to express the accuracy of the survey itself rather than by grade and classification which relate to accuracy of survey methods, you may do so by the following expression:

$$\text{Total Error} = \sqrt{(\text{X close error})^2 + (\text{Y close error})^2}$$

where the accuracy is the ratio of this expression to the total length of the survey. i.e. If the total X,Y error is 5 feet and the total survey length is 950 feet, the accuracy can be expressed as 5 : 950, or 1 : 190.

For plotting purposes, however, this error must be eliminated or compensated for. The process which best accomplishes this task for a closed-loop survey is a simple allocation of error (or corrections) to the components of the survey (angle and distance) in a proportionate manner. This method will close the loop such that the final point and the initial point are the same and is referred to in dry cave surveying as the compass rule closure method. In this method corrections are applied to each leg in proportion to the length of the leg by application of the following equation:

$C = EL \div Lt$ where

C = Correction

E = Total error in sum of X or Y with sign changes

L = Length of a leg

Lt = total length of survey

The compass rule closure method alters the length of each leg and each angle by proportionately allocating errors throughout the complete line plot to close the loop for drafting purposes.

It should be recognized that higher grade surveys require the use of a tape in determining distances or certainly in verification. Therefore, there will be an overwhelming probability that the majority of errors will be in the angular measurements determined by the compass rather than in the distance measurements. The loop closure process should take this into consideration.

For open-loop surveys, of course, there is no such thing as loop closure because there is no loop. Errors must be determined during the survey process by verification procedures such as tape measure verification, redundant or front/back angle measurements and triangulation. Without verification, errors will be undetected.

## DRAFTING

Once the data has been tabulated and the loops closed and error compensation completed, you are ready to proceed with the drafting of the working map. This process is best divided into segments for workload distribution or simply to make it easier to arrange the various segments when you structure the complete map. Obviously, this drafting should be done in pencil and should entail the drawing of the complete map of the cave with all limits, features, cross sections and notations as well as notes, scales, north arrows and legends using the standard symbology discussed in the prior section.

After laying out the map framework and plotting the survey line (line plot), the first step is to define the outer limits or walls of all chambers and passages. Next the cross sections and special views should be drawn in, and a line of section should be drawn at or across the location of the cross section. An arrow on the line of section should indicate the direction of view. We suggest using the symbol Vp (viewpoint) to indicate the exact point from which a particularly important cross section or feature is viewed, so the reader of the map will be able to duplicate that particular image if he places himself in the Vp position.

As discussed in the prior section, the symbology used in inserting details and features should be individualized as much as possible to represent the feature being noted. For example, a boulder should be annotated with the boulder symbol and the symbol drawn to the same shape as the actual shape and relative size of the boulder in order to represent a likeness as close as possible to the actual. The final draft of the map should resemble the cave as closely as possible so the reader should be

able to recognize the actual features. This is the primary purpose of a higher grade and higher classification survey.

Next come the lettering considerations, which are several, and are important to the overall value of the map. The lettering layout should be optimized on the working draft to enhance the overall balance. The scale, the title, the north arrow, as well as the notes, legends and borders should be placed about the map framework such that all descriptions, numbers and notations are in the most appropriate places.

There are five basic steps in the drafting process:

1. All map segments are drawn to scale on quadrille paper. This includes all passages, features, title block, notes, North arrow, scale bars, etc.

2. The segments are assembled on a drawing board and overlaid with a quadrille vellum or tracing paper in final scale. The individual segments are arranged to achieve the final layout with attention to overall impression, readability, interpretation, emphasis, aesthetics, and so on.

3. Pencil tracings are made onto the tracing paper. Follow up here with necessary editing, corrections, etc. This is the working drawing.

4. Duplicate this working drawing and distribute to the rest of the survey team members for their edit, additional inputs and critical critique.

5. Incorporate the team inputs on the working drawing. This is the final tracing template.

After completion of the tracing template, a final verification and confirmation should be done as necessary. This is your last chance to make corrections! From here on it will be in ink.

Now you may proceed to the final product, but first let's look at some special considerations.

**FINAL DRAWING - MEDIUM**

After completion of the working draft and tracing template, and all refinements have been incorporated, the final copy is traced and lettered in ink onto a reproducible medium. Here again you have several particular points of consideration.

The final tracing should be done on a translucent, rugged medium suitable for your reproduction process. We prefer a mylar vellum above all other choices. However, there are other choices depending on your personal preference. Probably the

least expensive is the same tracing paper we discussed in making the working draft. If you do use this medium for the final product, you should select a tracing paper with a high rag content which means a high percentage of cloth fiber. The higher the rag content, the more durable the paper. Consider also the smoothness of the inking surface. The less porous the surface, the higher the quality of inking; and the smoother the lines, the easier it is to make corrections.

Generally speaking, vellum is the best medium for drafting because it has excellent surface qualities; it comes in different sizes and thicknesses; it comes in different transparencies; and it reproduces well by any reproduction method whether it is xerox, diazo-blueprint, or photography. Vellum can also be obtained with a blue line grid overprint which is extremely useful as a layout tool and lettering guide.

Our preference is mylar which is very dimensionally stable (does not shrink or expand with changing temperatures) and virtually cannot be torn. It is certainly the most durable and takes ink well. Its disadvantages are that it is damaging to the fine points of inking tools and pens, and it is very expensive. You will do well to solicit advice from your local drafting and engineering supply store when it comes to the final selection.

## SPECIAL TOOLS

There are also some special tools you will need in order to do a respectable drafting job on the final map. This listing is by no means all inclusive but is an optimum combination of tools required to do a professional final drawing in ink.

- Drafting board or table. Depending on the size of the map to be drawn, a drafting surface can range from a commercial drafting board to a homemade solution such as a door covered with a smooth vinyl covering made for drafting board surfaces.

- Pens. There are a number of different types of drafting pens available. Above all we recommend the rapidograph type. Even though rapidograph is a brand name, it is a reservoir type of pen which is manufactured by several different companies. Rapidograph has become such a standard that it is referred to generically in the same manner as xerox and kleenex.

The all metal pen or jewelled pen tips are preferred over the plastic as they can be used very effectively with a lettering set. Rapidograph pens come in twelve sizes relating to line widths shown in Figure 12-5. Ruling and contour pens are always contained in an engineer's drafting set and are very useful in drawing long smooth straight lines such as borders and for drawing curves freehand, although the latter requires a great deal of practice.

| WIDTH INCHES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .008 | .010 | .013 | .017 | .021 | .026 | .035 | .043 | .055 | .067 | .083 | .098 |
| **PEN SIZE** | | | | | | | | | | | |
| 0000 | 000 | 00 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

Fig. 12-5 Rapidograph Pen Sizes

- Engineer's drafting set. In addition to the standard ruling and contour pens mentioned above, the standard drafting set contains several additional tools that are necessary such as dividers and compasses.

- Scale rule. The standard three-sided scale rule is needed for drafting to scale and is calibrated in 10, 20, 30, 40, 50, and 60 units per inch.

- T square, templates and triangles. If you are fortunate enough to have access to a drafting machine, you have little need for a T square. However, the standard 30/60 and 45 degree triangles are absolute necessities as is a good supply of templates - squares, rectangles and circles - and french curves.

- Protractors. Either a half circle or a full circle protractor will be required unless a drafting machine is used. These are an absolute necessity if the distance-angle method of constructing line plots is used rather than the cartesian coordinate method.

- Lettering set. Although free hand lettering is possible, it takes an unusually talented draftsman to letter in a consistent style. Certainly most draftsmen prefer to use some sort of mechanical lettering, lettering transfers or a lettering set. Lettering templates, of course, can be used, but my preference is a lettering set. There are several such sets available in drafting and engineering supply stores. The most popular of these is the Leroy lettering set made by K & E. These sets come with lettering guides ranging in size from .08 inch to .5 inch and a variety of styles. The cost of a complete set typically is over $200, although the guides and scriber may be purchased separately. If you prefer not to invest in a lettering set, lettering templates are available for use with rapidograph pens and can yield excellent results. Also, a Leroy guide and pen holder can be used with Rapidograph pens eliminating the need for a complete Leroy set.

- Other supplies. Several other items are necessary such as erasers (art gum or pink pearl) and razor blades or Exacto knives for removing ink. Additionally you might find talc

or liquid paper sealer useful to seal the pores in the paper surface prior to inking and especially after making corrections to an inked surface prior to reinking.

One final point regarding special cartographic tools, supplies and drafting aids. There is a large variety of preprinted symbols, lettering of all types and shading or screening films that are made to be transferred from an acetate sheet directly to the vellum simply by placing the image to be transferred in place on the vellum and rubbing the opposite side of the acetate sheet with a smooth surface or burnishing instrument. The image comes off the acetate and adheres to the vellum via a wax base bonding agent. Probably the most popular of these aids are the Chartpak types made by Avery Products Corp. Ziptone transfers are popular also. Use care in reproduction, however, because heat in the reproduction process can melt the wax adhesive and loosen or destroy the bond. Some of these products are advertised as heat resistant, so you might favor these to be on the safe side.

Once you have the proper drafting tools and supplies assembled, you are ready to ink the final product.

## DRAFTING CONSIDERATIONS - THE FINAL PRODUCT

Before you put pen and ink to paper (or vellum), there are several points of consideration here that are key to the drafting process. Each is important to the overall effectiveness of the map, so let's discuss them one at a time.

Generally speaking, professional draftsmen tend to organize their work in a logical order or progression when it comes to inking. This progression begins with all lettering. There are two reasons for this:

- First, lettering takes priority and where lettering may conflict with a line, the letter is inserted first and the line is broken to allow the letter.

- Second, this order is easier when it comes to making corrections or changes.

The style, size and boldness of the lettering, as well as the location, all work together to convey the information on the map and to make it understandable. You may choose to use Leroy, to use transfers, to use templates or to use typesetting, depending on personal preference. You should, however, restrict the sizes of the various letters and numbers to three or no more than four different sizes. Otherwise you lose the emphasis that size implies and, therefore, lose some of the capability of the map to communicate. Of particular importance here is the size of all lettering on the map if the map size is likely to be reduced or enlarged in reproduction. In this case the final size must be

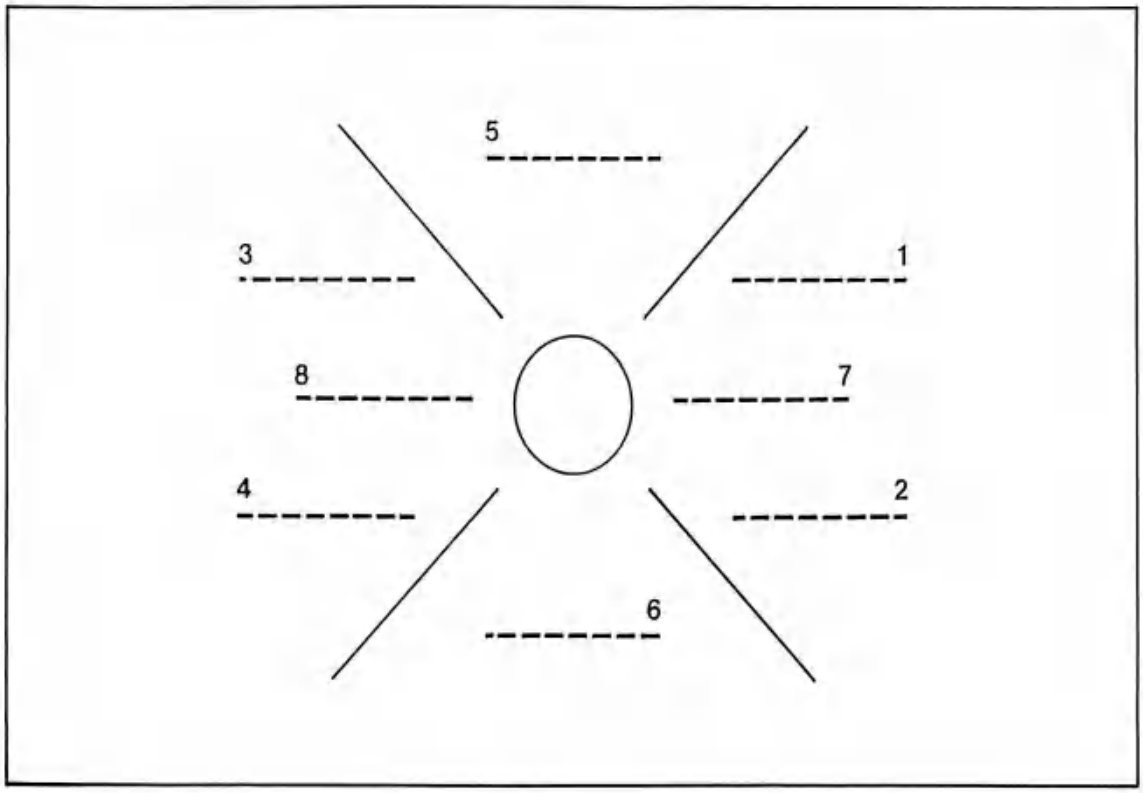



Fig. 12-6 Lettering Position Preference Guide

taken into consideration for basic readability as well as emphasis.

Positioning of lettering is also important, and a standard drafting procedure serves well to guide you here. Generally speaking, there is an order of preference in placing lettering around a point or feature. This guide is shown in Figure 12-6.

Lettering should always be parallel to the title block unless there is very good reason to deviate. Never letter upside down.

After lettering, come the north arrow and scales, then the passage outer limits, and finally the details, features and cross sections.

Line thickness is another very important consideration and, like lettering size, serves to communicate an emphasis or a shift in emphasis to a particular feature. A good rule of thumb generally used by most professional draftsmen is that minimum line thickness in the final reproduced copy of the map should not be less than 0.15 inch for good readability. For 1:1 reproduction, pen size 0 is the smallest size which will meet this requirement.

Another good guideline is that line widths should differ at least by a factor of two to be distinctively different.

Otherwise distinction and differentiation are lost. Keep in mind also that line width, like lettering size, is proportional to emphasis. It is generally agreed that the cave passage walls or outer limits would be more important and therefore should be emphasized more than the scale or the north arrow, for instance. A warning, on the other hand, should be bold and wide. Therefore, the line widths and lettering sizes should be chosen accordingly.

A couple of points on north arrows here. A north arrow should always be shown on the map in magnetic north. If magnetic north only is used, the arrow should have half a barb or a barb with one side light and one side dark. If true north is shown, the arrow should have a full barb. If both true north and magnetic north variation are shown, they both should be shown with arrows with their respective barb identifiers. Figure 12-7 shows samples of these.

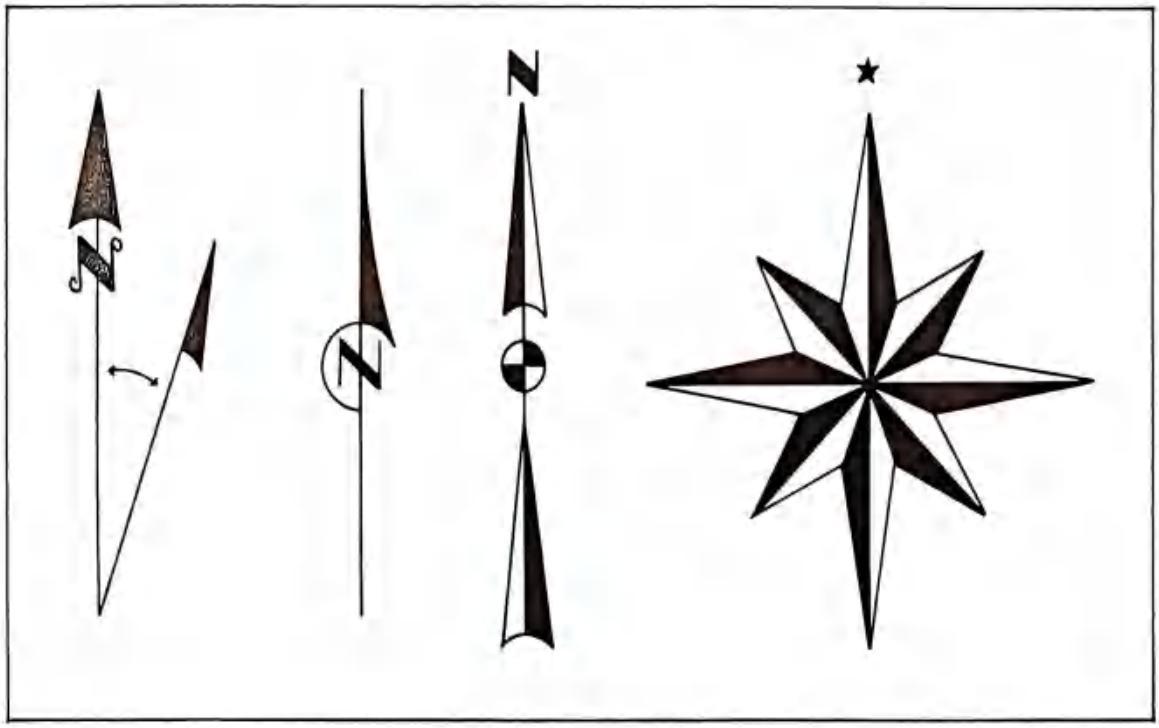



Fig. 12-7 North Arrows

A compass rose also may be used and may well add some appeal to the map. However, keep in mind that the north arrow or a compass rose is an essential but subordinate piece of data on the map and should be emphasized accordingly.

Scales, of course, also should be included on every map. There are two principal considerations regarding scales:

- First, if the map is ever likely to be reduced or enlarged in reproduction, do not use a stated scale. That would be a statement such as "1 inch = 50 ft." Obviously, if the map size is ever changed through reproduction, 1 inch would no longer

equal 50 feet! The better approach to scale is a bar graph divided into convenient equal parts (typically at least 4) with the units of measure noted. We have standardized in a scale bar numerically noted in standard measure (feet) on the upper side and metric measure (meters) on the lower side.

- Second, remember to include two or more scale bars on the map if two or more scales are used in the drawing. Typical would be one scale for a long cave passage and a 2X or 3X scale for cross sections. This procedure allows the reader to use dividers for relating distances to scale and offers another element of convenience to the user.

Another standard technique for adding emphasis to the overall map and for "gilding the lily," so to speak, is the addition of a border. A clean, rather heavy line completely around the outer limits of the paper does a tremendous amount toward focusing attention to the map itself and adds a substantial boost to the aesthetics.

Obviously, you must include the title box which must contain certain minimum information. The title box need not be bordered. This is a personal preference. We now use a check list and standardize our title blocks with the following information:

-Cave name. Name of cave (we give it one if it does not already have a commonly known name) and the county and state location. We recommend against exact location to prevent proliferation of its location to people who would be better off without it. (Non cave divers, for instance.)

- Date of survey. Completion date if the survey period was short. Period of survey if an extended time was involved.

- Names of survey team members and cave diving certification affiliations. It is also appropriate to add the names of the original cave explorers with appropriate notation, if known.

- Grade and class of survey per BCRA.

- Total length of survey. (This should include the total length of all lines surveyed but should not include working or verification lines such as radials unless so noted.)

- Total penetration. (Normally expressed in terms of distance from the entrance, but may be expressed as distance to the nearest exit. Appropriate notation should be made if more than one entrance exists.) Some surveyors include swim time to exit.

- U.S. Geological Survey Spring Identification Number. If none is assigned, so state.

- Name of draftsman or draftsmen. Usually the team unless one person literally does it all.

- Copyright notification and date.

The final elements to include are the notes of special information you as the surveyor and cartographer feel you need to bring to the attention of the reader/user and which have not been expressed elsewhere on the map.

The last item is the legend. This is a duplicate of every symbol you have used in the drawing of the map and an explanation of each symbol. The lack of a legend has severely limited the utility of many a map, and we consider its inclusion an absolute requirement. I feel very strongly on this point and consider any map without a legend as grossly incomplete.

## COMPUTER AIDED DRAFTING

The preceding discussion assumes that the average underwater cave surveyor will be creating his maps manually. That is, doing the complete project by hand, as we have described, at the drafting board.

However, there are other methods much more sophisticated and certainly involving much less time if one has access to a computer aided design and drafting or CADD facility. CADD is the utilization of a computer and plotter and the associated software to help the cartographer with the drafting process and drawing. Depending on the particular system involved, the capabilities and possibilities are limitless so far as application to cave mapping is concerned.

Although the use of CADD is currently considered very advanced as regards underwater cave mapping, we have applied certain CADD capabilities to do lettering, titling, blocking, bordering, notations and the like. Additionally, some underwater cave surveyors, Jeff Bozanic and Dennis Williams in particular, are beginning to apply CADD more extensively to the complete process from layout to survey line plotting.

By way of introduction to CADD, following is a very brief summary of just some of the capabilities of a basic CADD system which are applicable to underwater cave mapping.

Even the most basic CADD systems employ a powerful, but fairly easy to use, command language that typically requires little or no programming by the user. Each command name typically is representative of its function which minimizes the necessity for continuous reference to documentation. Commands are chosen from a user-generated menu or list of commands. Typically, once a command is selected the machine prompts the user for the additional input or information in order to execute the command.

The general drafting system of most CADD systems offers many, many capabilities in the creation of line styles, character fonts, symbols and the like and can do virtually any task a draftsman may wish. The CADD system can plot lines from coordinate inputs, it can create borders, and it can recall virtually any kind of information, graphic or otherwise, from memory. It can automatically do dimensions from point to point, and it can draw any shape from its vocabulary of lines, arcs, circles, squares, rectangles and other stored graphic functions.

Some versions of CADD systems offer some very intriguing capabilities which are applicable to cave mapping. A 3-D visualization mode is one of these. This is a mode of drafting which generates the capability to produce a three-dimensional representation from a two-dimensional drawing. The three dimensional model is created by assigning heights to planar graphics and extruding them into the third dimension. Once the 3-D model is constructed on the screen, it can be viewed from any position, with or without hidden line suppression. Isometric, axonometric, and two- and three-point perspective views can be produced automatically. Additionally, cross sections can be generated at any point on the drawing.

Versions of CADD with 3-D capability also have the ability to generate three-dimensional scenes from two dimensional drawings by using solids and color shading. This feature generates scenes by generating and manipulating solids. Each solid may be identified as any object related to the two-dimensional map symbology which may be moved, copied or rotated to create a view from any direction.

The use of CADD in underwater cave mapping has been applied minimally and by only a few surveyors to date. The technology certainly is here, and we surveyors have the ability to gather the input data which could take advantage of this technology. If you have access to a CADD system, you will be fortunate indeed and should make your results known to the underwater cave surveying community.

In the next edition of this book, or the advanced version, there will be a complete section on this methodology including several illustrations of CADD generated cave maps - three dimensions and all.

**SUMMARY**

A good quality map will contain at least the following elements and characteristics:

Plan View

Cross Sections as required to portray the significant cave features and shapes

Horizontal Profile if required to portray vertical uniqueness

Scale Bars (in feet and meters)

Legend

Notations

North Arrow

Title Block

Border

Cartography is certainly much more involved than merely sitting at a drafting board and drawing. There are many, many decisions to be made and numerous choices. Some choices are better than others and result in higher quality end products.

The art of cartography is an art of communicating, and numerous skills are involved. Some of the cartographic processes are technical in nature and require some mathematical exercises. Others are more artistic in nature and require different perceptions and a sensitivity to visual communication. Special tools and drafting aids are required, and certain standard rules of graphic art must be applied in order to do the job properly. The quality and accuracy of a poor survey cannot be improved by good cartography. However, poor cartography can ruin an otherwise excellent survey.

There are more advanced techniques and state-of-the-art equipment available in the form of computer aided design and drafting, or CADD systems, that can greatly simplify the cartographic process. However, this technology has been applied only on a very limited basis to date, but it does have tremendous capability for those who have access to CADD equipment.

If you follow these steps carefully and give due consideration to the points noted here, you will be able to do a very professional job of putting your survey data on paper and will be proud of the results. Not only that, others will be able to enjoy and to benefit from your efforts.

Note: Chartpak, Exacto, Kleenex, Leroy, Rapidograph, Xerox and Ziptone are all registered trademarks.

# SECTION 13

## PUBLICATION AND COPYRIGHT

### INTRODUCTION

Well now .... you're in the home stretch! Publication and Copyright. Now that the survey is done, the data is crunched and the rigors of cartography have been mastered to yield a quality vellum ready for printing, you proceed to the final phase.

Publication can and does take several forms and, in fact, has a relationship with the copyright process. So, before you take your vellum to the engineering supply store or to the local architect for blue lines or to the local Postal Instant Press for xerox or photographic reproduction, you should consider copyright.

Actually, you should make a deliberate decision as to whether or not you want copyright protection before you finalize the title block during the final drafting process. If you do not desire copyright protection, there is certainly no need to include a notification of copyright on the drawing. Technically, you have protection whether or not you include the notification, even if your map is not published. However, if your map is published with the notification by you or any one else, and you fail to comply with the requirements of the copyright laws, you could expose yourself to some liability. Therefore, you should be familiar with the general provisions of the statutes.

### THE COPYRIGHT LAW - GENERAL PROVISIONS

What, exactly, is copyright? Why or how does it apply to a map of an underwater cave? Should you register for copyright? Is it necessary? And so on. Let's answer these questions by taking a brief look at the copyright laws and then extracting the highlights that would be applicable to the underwater cave surveyor.

Since 1909, the copyright law of the United States remained unchanged until January 1, 1978, when the Copyright Act of 1976 (Title 17 of the United States Code) went into effect. This broad revision to the statutes both changed and streamlined many provisions of the basic legislation.

Quoting in part from Circular 1, Copyright Office, Library of Congress, "Copyright is a form of protection provided by the laws of the United States .... to the authors of original works

of authorship including .... literary, artistic and certain other intellectual works. This protection is available to both published and unpublished works. [Emphasis added] Section 106 of the Copyright Act generally gives the owner of copyright the exclusive right to do and to authorize others to do the following:

- To reproduce the copyrighted work....

- To prepare derivative works based upon the copyrighted work

- To distribute copies of the copyrighted work to the public by transfer of ownership, lease or lending

- To display the copyrighted work publicly."

A violation of any of the rights provided to an owner of copyright is illegal. However, although the rights seem broad in scope, they are not unlimited, and there are provisions in the law to allow for use. These provisions generally lie in the areas of "fair use" under section 107 and "compulsory license" wherein certain uses of copyrighted works are permitted under provision of payment of use fees or royalties.

**WHAT IS PROTECTED**

Copyright protection under law becomes effective for original works of authorship as soon as they become fixed in a tangible form of expression, and the fixation does not need to be directly perceptible so long as it may be communicated. This would apply to survey data, notes and sketches just as it would to computer software. For your purposes this would include all survey data in all forms inclusive of the final maps, computer programs and audio visual data. There are, however, some subtle differences as to which categories they might be registered under since computer programs and most forms of compilations are registerable as "literary works", whereas maps, graphics and blueprints are registerable as "pictorial, graphic, and sculptural works."

**WHAT IS NOT PROTECTED**

There are also several other categories of material that are not eligible for copyright protection. For example, titles, names, phrases, slogans, familiar symbols and designs are not registerable. Neither are ideas, methods, systems, processes, concepts, and discoveries, nor is information that is common property and contains no originality of authorship such as certain types of charts and tables taken from public documents or other common sources. The information on a cave map is not protected. The map is. That is to say, anyone who has access to

the map may use that information. However, he may not reproduce, copy, display or distribute it.

## SECURING COPYRIGHT PROTECTION

The method by which copyright protection is secured under the present statute is generally misunderstood. Note this: "No publication or registration or other action in the Copyright Office is required to secure copyright under the present law, unlike previous law, which required either publication with the copyright notice or registration in the Copyright Office," to quote from the Library of Congress. However, there are some distinct advantages to registering for copyright protection and publication.

## PUBLICATION & COPYRIGHT

Although publication per se is not pivotal to gaining copyright as it was under prior law, it is still very important in the current process. Within the law, publication is the distribution of copies of the work to the public by sale or other transfer of ownership or by rental, lease or lending. The offering to distribute copies for purposes of further distribution or public display also constitutes publication, although the public display of a work by and of itself does not constitute publication.

"So what," you might say. Well publication is an important concept in the copyright law since upon publication, several significant considerations follow:

- Publication of copyrighted material should bear notice of copyright as discussed later.

- Works published in the United States bearing notice of copyright must under law be deposited with the Copyright Office.

- Publication can affect the limitations of the rights of the owner.

- The year of publication bears on the term of copyright protection in certain instances.

- Timely publication and registration has a bearing on the recovery of defense costs in the event of infringement and ensuing litigation.

- Deposit requirements are different for published and unpublished works.

Whenever publication is made of a work for which copyright

protection is desired, notice of copyright must be made visually perceptible. The symbol ©, letter C in a circle, is the normal symbology of notification. However, the word "Copyright" or the abbreviation "Copr." may be used. Additionally the year of first publication and the name of the copyright claimant must be included. The Copyright Office has issued regulations concerning the form and position of the copyright notice in the Code of Federal Regulations. However, for cave maps you may assume that copyright notice within the title block is sufficient.

## UNPUBLISHED WORKS

A subtle but important point here bears on unpublished works. An unpublished work, as may be the case with a cave map, has no actual requirement to bear the copyright notification; however, it is strongly recommended that the creator of such a work affix a statement such as "Unpublished © 1987, Jane Jones" to any and all copies that leave the owner's control. Otherwise, an inadvertent publication without notice could take place.

## PUBLISHED WORKS & REGISTRATION

Although copyright registration is not required for unpublished works, the Copyright Act does set forth a mandatory requirement for deposit of copies of any work published, inadvertently or otherwise, with the notice of copyright affixed. The owner of the copyright actually has a legal obligation to deposit with the Copyright Office, within three months of publication, two copies for use by the Library of Congress. Failure to make this deposit after publication with notice can result in legal remedies including fines and other penalties. Copyright protection for the work, however, is still provided.

Generally speaking, copyright registration and deposit is a legal formality to create a public record of the facts of a particular work, and even though registration is not required, the law provides a number of inducements to encourage registration. Some of the advantages are:

- Registration does in fact create a public record of claim.

- Registration is necessary before any infringement suits may be filed in court.

- Timely registration will establish prima facie evidence in court of the validity of the copyright and the facts on the certificate.

- Registration within three months after publication or

prior to an infringement will allow the recovery of statutory damages and attorney fees by the owner in event of court actions. Otherwise, only actual damages and lost profits can be recovered.

Although the law encourages registration immediately upon publication and requires it prior to an infringement suit, registration may be made at any time. The normal term of copyright is for the duration of the author's life plus 50 years. In the event of coauthors or cocreators, the term is normally 50 years beyond the life of the surviving creator.

## TRANSFER OF RIGHTS

Transfer of the exclusive rights of copyright is not valid unless done so in writing and is signed by the owner of these exclusive rights. Transfer of non exclusive rights may be made by verbal agreement although a written agreement is preferred. A copyright is a personal property right and comes under the laws, regulations and provisions of state laws which govern the ownership, inheritance or transfer of personal property as well as terms of contracts or conduct of business. Transfer of copyright rights is normally done by contract, and the Copyright Office does not legally need to be involved. However, I would suggest strongly that any transfer of copyright ownership be copied to the Copyright Office for recordation since formal recordation provides certain legal advantages. Furthermore, recordation may be required to validate the transfer involving third parties.

## THE REGISTRATION PROCESS

OK. So all this is very interesting, and you want to copyright your map. Who can do it? How about the forms and paper work? What's the procedure? How much does it cost?

Normally, the creator or author of the work is the owner and may file. However, anyone who has ownership rights may also file. These may be people or organizations which by transfer of rights or by employment have right of ownership of the work. Normally, in a cave survey, this would be the survey team members, individually or collectively.

Forms are available from the Copyright Office, Library of Congress, Washington, D.C. For original registrations, the following forms apply:

- Form VA for published and unpublished works of the visual arts (pictorial, graphic, sculptural works). Use this form for maps.

- Form PA for published and unpublished works of motion picture or audio visual form. Use this form for video tapes.

- Form CA for supplementary registration to correct or to amplify information given in the Copyright Office record of an earlier registration. Use this form for survey continuances or additions.

- Form SE for serials, works issued or intended to be issued in successive parts bearing numerical or chronological designations.

Needless to say, there are numerous other forms available; however, those listed here are all that might be required to copyright any form of an underwater cave map.

The registration procedure is a simple one and requires only three items:

1. A properly completed application form. Form VA for a cave map. A blank form VA is included as Appendix D.

2. A nonreturnable filing fee of $10 for each application. The $10 fee must be in the form of a check, a bank draft or a money order. Cash will not be accepted.

3. A nonreturnable deposit of the work being registered. One copy if unpublished. Two copies if published.

Note. After the registration process is completed, the application form becomes part of the official permanent records of the Library of Congress so the forms must meet archival standards. Consequently, only Copyright Office form blanks should be used and only black ink or a typewriter should be used.

Upon completion of the three elements of application above, all three should be mailed **together** to:

Register of Copyrights
Copyright Office
Library of Congress
Washington, D.C. 20559

**If all three elements (the application, the fee and the deposit) are not received together, the application will not be processed** and will be disposed of in accordance with section 408 which specifies disposition of each element under varying types of registrations.

**NOTIFICATION OF COPYRIGHT**

Once the decision has been made to file a registration for copyright, one needs only to add the notification of copyright to the title block of the map. Don't forget to include the date (year) of publication and name(s) of the claimant(s). Inclusion of the copyright notification involves no more than the stroke of

a pen, and the filing procedure is simple, so my recommendation is to copyright each of your maps. We list all the members of our survey team as claimants, and we make it a point to allow only non exclusive use of our maps. If we were ever to convey exclusive rights to anyone, we would be sure to do so in a written, signed document and have it recorded by the Copyright Office.

**TIME PERIOD**

Processing of copyright registration by the Copyright Office, Library of Congress normally takes six to twelve weeks. Any errors or points of clarification that have to be resolved by correspondence will add substantial delays to the already seemingly slow process. I have had experiences where one question by the Copyright Office has added over six weeks to the process! Not only that, the Copyright Office even has rules governing correspondence, queries and answers to queries! My advice: **Do it right the first time**!

With the inclusion of the "Circle C" in the title block, the vellum is ready for final printing or publication via whatever process you have need for. You will be proud of the results, and other people will have the benefit of your efforts.

# SECTION 14

## IN CONCLUSION

At the outset I stated that Frank and I certainly do not hold ourselves up as experts in underwater cave surveying. I did say, though, that we have spent considerable time under water together and even more time on the surface working on tools and techniques, methods and modifications. We have made just about every surveying error there is - several times - and we have made very deliberate efforts over a period of many, many months to keep extensive records so we could document what we have learned. We generated a collection of knowledge and experiences certainly useful to us and which I have tried to organize and to articulate for you as a data base. A starting point for you if you are just beginning in underwater cave surveying. A supplement of information for the experienced cave diver already into surveying.

Let me reemphasize that, although some special tools are required, surveying per se is primarily procedural and, therefore, technique and understanding are at the heart of the process. I have shared the best of ours with you and hope that you will continue to refine what is offered here in **Basic Underwater Cave Surveying**. Let me also reemphasize that this art, or science if you will, is embryonic and has much maturing ahead. Both Frank and I take pleasure in being able to contribute our little bit to furthering the art of surveying underwater caves and to the sport of cave diving as well.

Let me also highlight safety once again and allow the ditty writer to make one last and, hopefully, expanding mind awareness contribution:

David liked to dive in caves
He often bent the rules
Now he's resting in his grave
David was a fool

Had he not pushed his luck a way
As he would often do
He'd still be with us here today
His buddy would be too

We feel that surveying possibly adds some risks to normal cave diving. However, we also feel that proper attention to safety considerations when developing and refining techniques and procedures will reduce or eliminate these risks or perhaps even turn them to advantages. Properly developed procedures should

lessen the inherent risks rather than increasing them.

The cartographic process is a challenge unto itself to anyone who has had no training or experience in graphic art. Not only that, cartography is the culmination and exemplification of the entire process - the final phase - the coming together of all the planning, the diving, the data taking - the blooming of the flower to behold.

There is no doubt that you will gain tremendous satisfaction from your first survey. Once done - addicted.

It has indeed been a pleasure to be able to organize our thinking, to summarize, and to share our data base with you. I have enjoyed it immensely.

In conclusion, I wish you fun, success and safety in your underwater cave surveying.

John Burge

# SECTION 15

## ILLUSTRATIONS


| FIG. | TYPE | TITLE |
|---|---|---|
| 5-1 | Illustr. | The Survey Process |
| 5-2 | Table | BCRA Standards of Accuracy |
| 5-3 | Table | Classification of Survey Detail |
| 5-4 | Table | Grade/ Class Combinations |
| 5-5 | Illustr. | Six Point Line Plot - Gr 3 Closed Loop |
| 5-6 | Illustr. | Six Point Line Plot - Open Loop |
| 5-7 | Illustr. | Triangulation Required Gr 5 Accuracy |
| 7-1 | Photo | Survey Slates |
| 7-2 | Photo | Knotted Line Reel and Tape |
| 7-3 | Photo | Survey Station Markers |
| 7-4 | Photo | Permanent Fasteners |
| 7-5 | Photo | Surveyor's Helmet |
| 8-1 | Illustr. | Station Locations, Vertical |
| 8-2 | Illustr. | Station Locations, Sketch & Flow |
| 8-3 | Illustr. | Plumbing the Line with the Reel |
| 8-4 | Illustr. | Standard Hand Signals |
| 8-5 | Photo | Proper Hand Signals - #2, #7 |
| 8-6 | Illustr. | Line Plot |
| 8-7 | Illustr. | Circumsketch |
| 8-8 | Illustr | Features |

| | | |
|---|---|---|
| 8-9 | Photo | Fixing the Survey Slate |
| 8-10 | Illustr. | Avoiding Parallax Errors |
| 8-11 | Illustr. | Line Compass with Card Lock |
| 10-1 | Illustr. | Slate Format - Passage |
| 10-2 | Illustr. | Slate Format - Room |
| 10-3 | Illustr. | Slate Format - Sidewall Sketch |
| 10-4 | Illustr. | Survey Shorthand |
| 10-5 | Illustr. | Relative Station Positions |
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| 10-8 | Illustr. | Permanent Data Record |
| 10-9 | Illustr. | Working Line Plot |
| 11-1 | Illustr. Table | Conventional Underwater Cave Map Symbols |
| 12-1 | Illustr. | Station Survey Data |
| 12-2 | Illustr. | Angle/ Bearing Conversion by Quadrant |
| 12-3 | Table | Table of Cumulative Coordinates |
| 12-4 | Illustr. | Plot of Cartesian Coordinates |
| 12-5 | Table | Rapidograph Pen Sizes |
| 12-6 | Illustr. | Lettering Position Preference |
| 12-7 | Illustr. | North Arrows |

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# APPENDIX A

## BRITISH CAVE RESEARCH ASSOCIATION GRADINGS

| | |
|---|---|
| GRADE 1 | A sketch of low accuracy where no measurements have been made |
| GRADE 2 | May be used, if necessary, to describe a sketch that is intermediate between grades 1 and 3 |
| GRADE 3 | A rough magnetic survey. Horizontal and vertical angles measured to ± 2.5 degrees; distances measured to ± 50 cm; station position error less than ± 50 cm |
| GRADE 4 | May be used, if necessary, to describe a survey that fails to attain all of the requirements of grade 5 but is more accurate than grade 3 |
| GRADE 5 | A magnetic survey, horizontal and vertical angles accurate to ± 1 degree; distances accurate to ± 10 cm; station position error less than ± 10 cm |
| GRADE 6 | A magnetic survey that is more accurate than grade 5 |
| GRADE X | A survey that is based primarily on the use of a theodolite instead of a compass |

**CLASSIFICATION OF SURVEY DETAIL**

| | |
|---|---|
| Class A | All details based on memory |
| Class B | Passage details estimated and recorded in the cave |
| Class C | Measurements of detail made at survey stations only |
| Class D | Measurements of detail made at survey stations and whenever necessary between stations to show significant changes in passage shape, size, direction, etc. |

RECOMMENDED GRADING/CLASSIFICATION COMBINATIONS

| | |
|---|---|
| Grade | 1 A |
| Grade | 3 B or 3 C |
| Grade | 5 C or 5 D |
| Grade | 6 D |
| Grade | X B, X C, or X D |

1. The above table is a summary and is intended only as an aid memoire; the definitions of survey grade given above must be read in conjunction with the additional comments made in the B.C.R.A. book "Surveying Caves." The more important comments are summarized below.

2. In all cases it is necessary to follow the spirit of the definition and not just the letter.

3. The term accuracy, used in the definitions, means the nearness of a result to the true value; It must not be confused with precision which is the nearness of a number of repeat results to each other, irrespective of their accuracy.

4. To attain grade 3 it is necessary to use a clinometer in passages having an appreciable slope.

5. It is essential for instruments to be properly calibrated to attain grade 5 -- details given in "Surveying Caves."

6. A grade 6 survey requires the compass to be used at the limit of possible accuracy, i.e. accurate to ± 0.5 degree; clinometer readings must be to the same accuracy. Distance and station position must be accurate to at least ± 2.5 cm and will require the use of tripods or similar techniques.

7. A grade X survey must include on the drawing notes on the type of instruments and techniques used, together with an estimate of the probable accuracy of the survey compared with grade 3, 5 or 6 surveys.

8. Grades 2 and 4 are for use only when, at some stage of the survey, physical conditions have prevented the surveyor from attaining all the requirements for the next higher grade and it is not practical to survey again.

9. The tabular summary above must not be republished without these notes.

# APPENDIX B

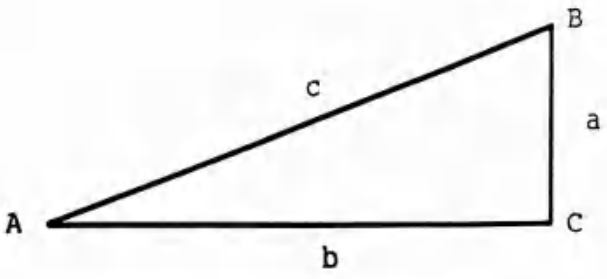
## TRIGONOMETRY IN A NUT SHELL

Underwater cave surveying necessitates the manipulation of data regarding the relationship between angles and distances. This involves the use of trigonometry which is based on the study of the interrelationship between the angles and the sides of triangles.

There are two classes of triangles - right triangles and oblique triangles. The right triangle has one angle = 90 degrees. The oblique triangle has no angle = 90 degrees. Both classes of triangles have a group of relationships which are expressed as trigonometric functions. These functions are explained in the following examples:

**RIGHT TRIANGLES**

| | |
|---|---|
| Sin A = a÷c | Sin A = Cos B |
| Cos A = b÷c | Tan A = Cot B |
| Tan A = a÷b | Sec A = Csc B |
| Cot A = b÷a | Cos A = Sin B |
| Sec A = c÷a | Cot A = Tan B |
| Csc A = c÷b | Csc A = Sec B |




For any angle of A, the actual values of the functions have been calculated as a table of trigonometric functions. Many hand calculators have these functions built into their systems. Any part of the triangle can be determined from any two other parts. For example:

$a = c \sin A$ $\quad b = c \cos A$ $\quad B = 90 - A$

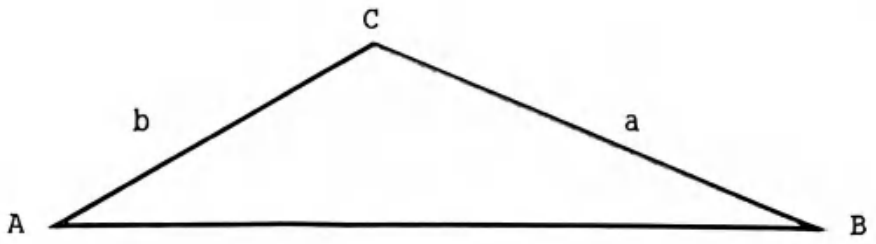
$c = a \div \sin A$ $\quad c = b \div \cos A$ $\quad c^2 = a^2 + b^2$

When the angle exceeds 90 degrees, the sign of the function may change. The following is a list of the sign changes for the basic functions.

| | | |
|---|---|---|
| Sin 0 to 90 + | Cos 0 to 90 + | Tan 0 to 90 + |
| Sin 91 to 180 + | Cos 91 to 180 - | Tan 91 to 180 - |
| Sin 181 to 270 - | Cos 181 to 270 - | Tan 181 to 270 + |
| Sin 271 to 360 - | Cos 271 to 360 + | Tan 271 to 360 - |

OBLIQUE TRIANGLES

When three parts of an oblique triangle, including one side, are given, all the other parts of the triangle can be determined.

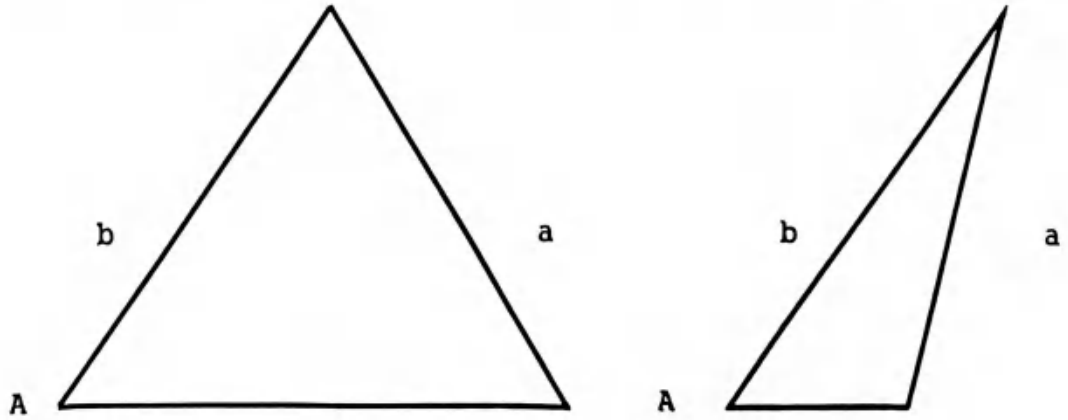



Example 1: Given one side and any two angles (Law of Sines)

a ÷ Sin A = b ÷ Sin B = c ÷ Sin C
(Note that A + B + C = 180)

Using the Law of sines: a = b Sin A ÷ Sin B, etc.

Example 2: Given are two sides and the angle opposite one of them. Here are two solutions to the problem as given below. Note that the Law of Sines can also be used for a solution.




Example 3: Given the two sides and the included angle, the following equation can be used:

Tan B = Sin A ÷ c - b Cos A

a = Sin A X b ÷ Sin B

C = 180 - [A + B]

Example 4: Given three sides and an angle, the following Cosine rule can be used:

$$a^2 = b^2 + c^2 - 2bc \text{ Cos } A$$

$$b^2 = c^2 + a^2 - 2ac \text{ Cos } B$$

$$c^2 = a^2 + b^2 - 2ab \text{ Cos } C$$

The angles can be found by using:

$$\text{Cos } A = a^2 - b^2 - c^2 \div -2bc.$$

Trigonometric identities can often be used in surveying. It is important to know what is available without having to derive each one. The following identities might prove to be useful:

$$\text{Sin } A \div \text{Cos } A = \text{Tan } A \qquad \text{Sin}^2 A + \text{Cos}^2 A = 1$$

$$\text{Tan}^2 A + 1 = \text{Sec } A \qquad \text{Cos } A = 1 \div [1 + \text{Tan } A]$$

Many other identities can be found in trigonometry text books and tables if necessary.

Normally, in underwater cave surveying the trigonometric manipulation of the data is limited to the simple basic functions of a right triangle using Sine, Cosine or Tangent. However, in more extended surveys where very long loops with many legs must be closed and in higher grade surveys where a lot of triangulation for verification is required, more extensive use of trigonometry is involved.

**Note: The foregoing discussion was derived in part from AN INTRODUCTION TO CAVE MAPPING, second edition, "MISSOURI SPELEOLOGY," Volume 21, numbers 1 - 2, pp 117-118.**

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# APPENDIX C

## ABBREVIATED TRIG TABLES

| Angle >> | Sine | Cosine | Tan | Cotan | |
|---|---|---|---|---|---|
| 1 | 0.01745 | 0.9998 | 0.01746 | 57.290 | 89 |
| 2 | 0.03490 | 0.9994 | 0.03492 | 28.636 | 88 |
| 3 | 0.05234 | 0.9986 | 0.05241 | 19.081 | 87 |
| 4 | 0.06976 | 0.9976 | 0.06993 | 14.301 | 86 |
| 5 | 0.08716 | 0.9962 | 0.08749 | 11.430 | 85 |
| 6 | 0.1045 | 0.9945 | 0.10510 | 9.5144 | 84 |
| 7 | 0.1219 | 0.9925 | 0.12278 | 8.1443 | 83 |
| 8 | 0.1392 | 0.9903 | 0.14054 | 7.1154 | 82 |
| 9 | 0.1564 | 0.9877 | 0.15838 | 6.3137 | 81 |
| 10 | 0.1736 | 0.9848 | 0.1763 | 5.6713 | 80 |
| 11 | 0.1908 | 0.9816 | 0.1944 | 5.1445 | 79 |
| 12 | 0.2079 | 0.9781 | 0.2126 | 4.7046 | 78 |
| 13 | 0.2250 | 0.9744 | 0.2309 | 4.3315 | 77 |
| 14 | 0.2419 | 0.9703 | 0.2493 | 4.0108 | 76 |
| 15 | 0.2588 | 0.9659 | 0.2679 | 3.7320 | 75 |
| 16 | 0.2756 | 0.9613 | 0.2867 | 3.4874 | 74 |
| 17 | 0.2924 | 0.9563 | 0.3057 | 3.2708 | 73 |
| 18 | 0.3090 | 0.9511 | 0.3249 | 3.0777 | 72 |
| 19 | 0.3256 | 0.9455 | 0.3443 | 2.9042 | 71 |
| 20 | 0.3420 | 0.9397 | 0.3640 | 2.7475 | 70 |
| 21 | 0.3584 | 0.9336 | 0.3839 | 2.6051 | 69 |
| 22 | 0.3746 | 0.9272 | 0.4040 | 2.4751 | 68 |
| 23 | 0.3907 | 0.9205 | 0.4245 | 2.3558 | 67 |
| 24 | 0.4067 | 0.9135 | 0.4452 | 2.2460 | 66 |
| 25 | 0.4226 | 0.9063 | 0.4663 | 2.1445 | 65 |
| 26 | 0.4384 | 0.8988 | 0.4877 | 2.0503 | 64 |
| 27 | 0.4540 | 0.8910 | 0.5095 | 1.9626 | 63 |
| 28 | 0.4695 | 0.8829 | 0.5317 | 1.8807 | 62 |
| 29 | 0.4848 | 0.8746 | 0.5543 | 1.8040 | 61 |
| 30 | 0.5000 | 0.8660 | 0.5774 | 1.7320 | 60 |
| 31 | 0.5150 | 0.8572 | 0.6009 | 1.6643 | 59 |
| 32 | 0.5299 | 0.8480 | 0.6249 | 1.6003 | 58 |
| 33 | 0.5446 | 0.8387 | 0.6494 | 1.5399 | 57 |
| 34 | 0.5592 | 0.8292 | 0.6745 | 1.4826 | 56 |
| 35 | 0.5736 | 0.8192 | 0.7002 | 1.4281 | 55 |
| 36 | 0.5878 | 0.8090 | 0.7265 | 1.3764 | 54 |
| 37 | 0.6018 | 0.7986 | 0.7536 | 1.3270 | 53 |
| 38 | 0.6157 | 0.7880 | 0.7813 | 1.2799 | 52 |
| 39 | 0.6293 | 0.7771 | 0.8098 | 1.2349 | 51 |
| 40 | 0.6428 | 0.7660 | 0.8391 | 1.1917 | 50 |
| 41 | 0.6561 | 0.7547 | 0.8693 | 1.1504 | 49 |
| 42 | 0.6691 | 0.7431 | 0.9004 | 1.1106 | 48 |
| 43 | 0.6820 | 0.7314 | 0.9325 | 1.0724 | 47 |
| 44 | 0.6947 | 0.7193 | 0.9657 | 1.0355 | 46 |
| 45 | 0.7071 | 0.7071 | 1.0000 | 1.0000 | 45 |
| | Cosine | Sine | Cotan | Tan | << Angle |

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# APPENDIX D

## COPYRIGHT APPLICATION FORM VA

**FORM VA**
UNITED STATES COPYRIGHT OFFICE

REGISTRATION NUMBER

VA VAU

EFFECTIVE DATE OF REGISTRATION

Month Day Year

DO NOT WRITE ABOVE THIS LINE. IF YOU NEED MORE SPACE, USE A SEPARATE CONTINUATION SHEET.

**1** TITLE OF THIS WORK ▼ NATURE OF THIS WORK ▼ See instructions

PREVIOUS OR ALTERNATIVE TITLES ▼

PUBLICATION AS A CONTRIBUTION If this work was published as a contribution to a periodical, serial, or collection, give information about the collective work in which the contribution appeared. Title of Collective Work ▼

If published in a periodical or serial give: Volume ▼ Number ▼ Issue Date ▼ On Pages ▼

**2** a NAME OF AUTHOR ▼ DATES OF BIRTH AND DEATH Year Born ▼ Year Died ▼

Was this contribution to the work a "work made for hire"? ☐ Yes ☐ No

AUTHOR'S NATIONALITY OR DOMICILE Name of Country OR Citizen of ▶ Domiciled in ▶

WAS THIS AUTHOR'S CONTRIBUTION TO THE WORK Anonymous? ☐ Yes ☐ No Pseudonymous? ☐ Yes ☐ No If the answer to either of these questions is "Yes," see detailed instructions.

NATURE OF AUTHORSHIP Briefly describe nature of the material created by this author in which copyright is claimed. ▼

**NOTE**
Under the law, the "author" of a "work made for hire" is generally the employer, not the employee (see instructions). For any part of this work that was "made for hire" check "Yes" in the space provided, give the employer (or other person for whom the work was prepared) as "Author" of that part, and leave the space for dates of birth and death blank.

b NAME OF AUTHOR ▼ DATES OF BIRTH AND DEATH Year Born ▼ Year Died ▼

Was this contribution to the work a "work made for hire"? ☐ Yes ☐ No

AUTHOR'S NATIONALITY OR DOMICILE Name of Country OR Citizen of ▶ Domiciled in ▶

WAS THIS AUTHOR'S CONTRIBUTION TO THE WORK Anonymous? ☐ Yes ☐ No Pseudonymous? ☐ Yes ☐ No If the answer to either of these questions is "Yes," see detailed instructions.

NATURE OF AUTHORSHIP Briefly describe nature of the material created by this author in which copyright is claimed. ▼

c NAME OF AUTHOR ▼ DATES OF BIRTH AND DEATH Year Born ▼ Year Died ▼

Was this contribution to the work a "work made for hire"? ☐ Yes ☐ No

AUTHOR'S NATIONALITY OR DOMICILE Name of Country OR Citizen of ▶ Domiciled in ▶

WAS THIS AUTHOR'S CONTRIBUTION TO THE WORK Anonymous? ☐ Yes ☐ No Pseudonymous? ☐ Yes ☐ No If the answer to either of these questions is "Yes," see detailed instructions.

NATURE OF AUTHORSHIP Briefly describe nature of the material created by this author in which copyright is claimed. ▼

**3** YEAR IN WHICH CREATION OF THIS WORK WAS COMPLETED This information must be given in all cases. ◀ Year

DATE AND NATION OF FIRST PUBLICATION OF THIS PARTICULAR WORK Complete this information ONLY if this work has been published. Month ▶ Day ▶ Year ▶ ◀ Nation

**4** COPYRIGHT CLAIMANT(S) Name and address must be given even if the claimant is the same as the author given in space 2. ▼

See instructions before completing this space

TRANSFER If the claimant(s) named here in space 4 are different from the author(s) named in space 2, give a brief statement of how the claimant(s) obtained ownership of the copyright. ▼

DO NOT WRITE HERE OFFICE USE ONLY

APPLICATION RECEIVED

ONE DEPOSIT RECEIVED

TWO DEPOSITS RECEIVED

REMITTANCE NUMBER AND DATE

MORE ON BACK ▶ • Complete all applicable spaces (numbers 5-9) on the reverse side of this page • See detailed instructions • Sign the form at line 8

DO NOT WRITE HERE

Page 1 of _____ pages

# COPYRIGHT APPLICATION FORM VA

EXAMINED BY — FORM VA

CHECKED BY

☐ CORRESPONDENCE Yes

☐ DEPOSIT ACCOUNT FUNDS USED

FOR COPYRIGHT OFFICE USE ONLY

**DO NOT WRITE ABOVE THIS LINE. IF YOU NEED MORE SPACE, USE A SEPARATE CONTINUATION SHEET.**

**PREVIOUS REGISTRATION** Has registration for this work, or for an earlier version of this work, already been made in the Copyright Office? **5**

☐ Yes ☐ No If your answer is "Yes," why is another registration being sought? (Check appropriate box) ▼

☐ This is the first published edition of a work previously registered in unpublished form.

☐ This is the first application submitted by this author as copyright claimant.

☐ This is a changed version of the work, as shown by space 6 on this application.

If your answer is "Yes," give: Previous Registration Number ▼ Year of Registration ▼

**DERIVATIVE WORK OR COMPILATION** Complete both space 6a & 6b for a derivative work; complete only 6b for a compilation. **6**

a. Preexisting Material Identify any preexisting work or works that this work is based on or incorporates. ▼

See instructions before completing this space

b. Material Added to This Work Give a brief, general statement of the material that has been added to this work and in which copyright is claimed. ▼

**DEPOSIT ACCOUNT** If the registration fee is to be charged to a Deposit Account established in the Copyright Office, give name and number of Account. **7**

Name ▼ Account Number ▼

**CORRESPONDENCE** Give name and address to which correspondence about this application should be sent. Name/Address/Apt/City/State/Zip ▼

Be sure to give your daytime phone number

Area Code & Telephone Number ▶

**CERTIFICATION*** I, the undersigned, hereby certify that I am the **8**

Check only one ▼

☐ author

☐ other copyright claimant

☐ owner of exclusive right(s)

☐ authorized agent of _____
Name of author or other copyright claimant, or owner of exclusive right(s) ▲

of the work identified in this application and that the statements made by me in this application are correct to the best of my knowledge.

Typed or printed name and date ▼ If this is a published work, this date must be the same as or later than the date of publication given in space 3.

_____ date ▶ _____

Handwritten signature (X) ▼

**MAIL CERTIFICATE TO** **9**

Certificate will be mailed in window envelope

Name ▼

Number/Street/Apartment Number ▼

City/State/ZIP ▼

Have you:
- Completed all necessary spaces?
- Signed your application in space 8?
- Enclosed check or money order for $10 payable to Register of Copyrights?
- Enclosed your deposit material with the application and fee?

MAIL TO: Register of Copyrights, Library of Congress, Washington, D.C. 20559

* 17 U.S.C. § 506(e): Any person who knowingly makes a false representation of a material fact in the application for copyright registration provided for by section 409, or in any written statement filed in connection with the application, shall be fined not more than $2,500.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1987 181—631/40,018 February 1987—100,000

# GLOSSARY OF TERMS

This glossary is a listing of terms which may not be familiar to the lay person. The definitions herein may be useful in understanding certain portions of the text.

**Azimuth**
Horizontal direction expressed in terms of angle as read from a compass.

**Bearing**
Direction expressed in terms of angle related to magnetic north. The azimuth direction of the compass lubber line.

**CADD**
Computer Aided Design and Drafting. The computer application of a drafting system which performs most drafting functions either automatically or at command of the operator.

**Cartesian coordinate**
Any two or three coordinates that locate a point in space and measure its distance from a given point of intersection in those planes. See also, Polar coordinate and Rectangular coordinate.

**Chartpak**
A registered trademark name for lettering and symbol transfers used in drafting.

**Compass card**
That part of a compass which embodies the needle and the magnetic element which rotates seeking magnetic north.

**Compass rule closure**
One of several methods of allocating errors and making corrections for drafting of traverse lines used in developing closed-loop surveys.

**Circumline**
The survey line around the circumference of a circular area. Normally around the perimeter of a room or chamber when surveying.

**Circumsketch**
The drawing or sketch of the outer limits or boundaries of a room or chamber beyond the circumline which is used as the reference.

Cumulative
Summing or integrating all the values.

Damped
Smoothed. A damped compass card is one which is controlled as to rate of turn. Moves slowly. Does not oscillate.

Diazo
Photocopy process whose production involves the use of a coating of diazo compound that is decomposed by exposure to light. A blueprinting process.

Granularity
Containing small units. A gauge with a scale calibrated in one unit increments would have a higher degree of granularity than one calibrated in ten unit increments.

Hysteresis
A retardation of the effect when the forces acting upon a body are changed. A lagging in the values.

Lubber Line
The line across a compass which is sighted for direction. The direction the compass is pointing as opposed to the needle which always seeks north.

Magnetic Deviation
The change in magnetic direction of a compass as caused by an external magnetic field.

Magnetic Variation
The change in magnetic direction of a compass by the relationship of a given location to the north pole. Although this variation changes slowly over years, it is generally considered constant for any one location.

Mylar
A strong, durable, translucent, plastic-like substance used as a drafting medium as opposed to paper which is much less durable.

Orthogonal
At right angle to, perpendicular, across, broadside.

Plumb
The use of a hanging weight to determine exact vertical alignment.

Polar coordinate
Either of two numbers that locate a point in a plane by its distance from a fixed point on a line and the angle this line makes with a fixed line. See also, Cartesian coordinate.

Rapidograph
: A registered trademark brand name for a reservoir tube type drafting pen. Also used generically to depict any similar type of drafting pen.

Rectangular coordinate
: A Cartesian coordinate of a Cartesian coordinate system whose straight-line axes or coordinate planes are perpendicular. See also, Cartesian coordinate and Polar coordinate.

Vellum
: A strong membranous material used as a drafting medium as opposed to paper. See also, Mylar.

# INDEX


A

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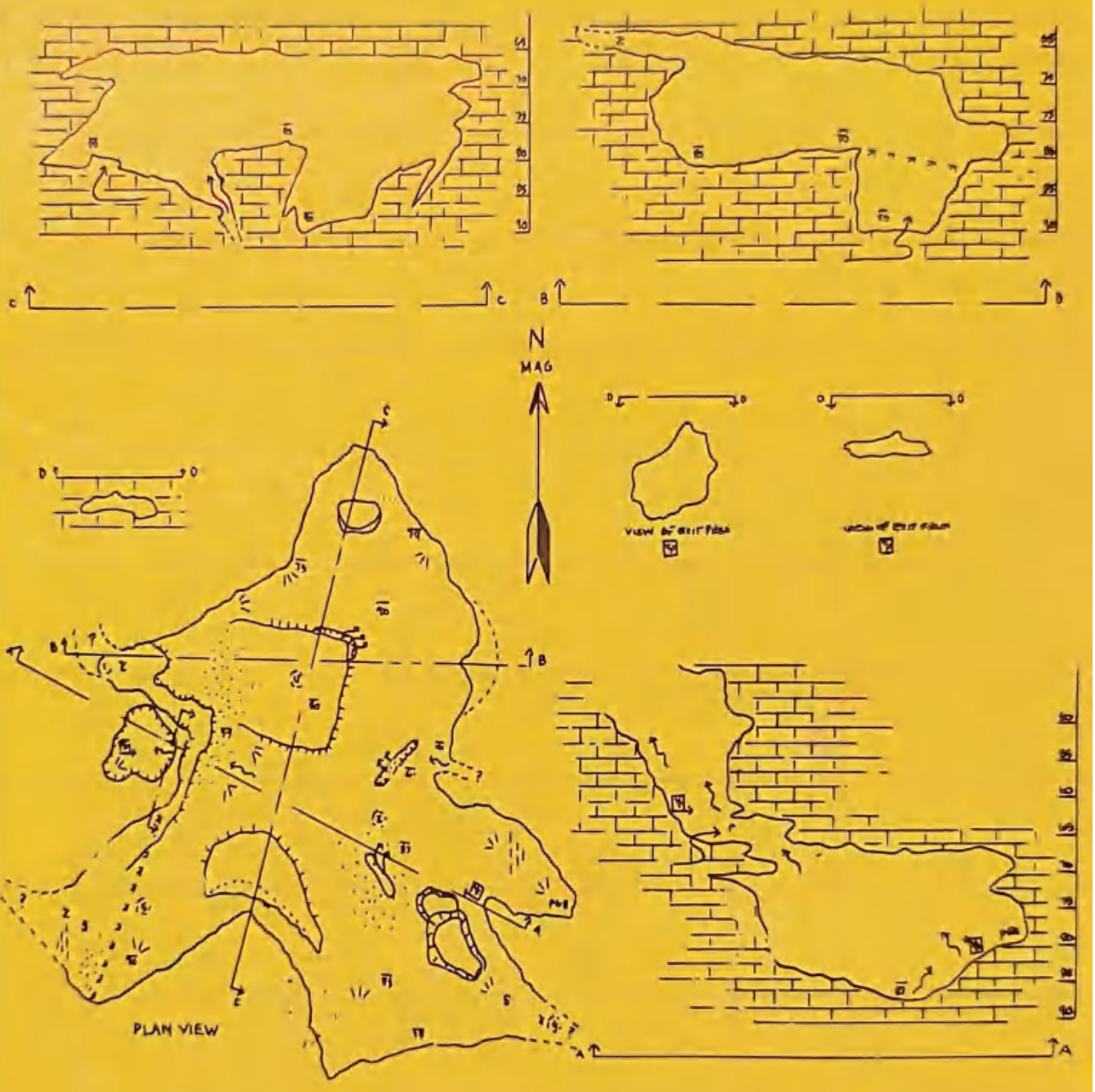


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